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NEW YORK, NEW HAVEN & HARTFORD RAILROAD,
COS COB POWER PLANT
Sound Shore ~~Road~~ *Drive*
Town of Greenwich
Fairfield County
Connecticut

HAER No. CT-142-A

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

MEASURED DRAWINGS

Historic American Engineering Record
National Park Service
Department of the Interior
P.O. Box 37127
Washington, D.C. 20013-7127

HISTORIC AMERICAN ENGINEERING RECORD

NEW YORK, NEW HAVEN & HARTFORD RAILROAD, COS COB POWER PLANT

HAER
CONN
1-GREW,
1979-

HAER NO. CT-142-A

Location: Town of Greenwich, on Sound Shore ^{State} Road. The site is next to New York, New Haven & Hartford Railroad tracks on the west bank of the Mianus River, Fairfield County, Connecticut.

UTM Coordinates:

	Zone	Easting	Northing
A	18	618060	4542880
B	18	618050	4542720
C	18	617900	4542680
D	18	617800	4542720
E	18	617800	4542820

Quad: Stamford, Connecticut 1:24,000

Date of Construction: 1905-1907; 1911-1912

Engineers: Calvert Townley; William S. Murray

Electrical Contractor: Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania

Design/Construction: Engineering Department-New Haven RR; Westinghouse, Church, Kerr and Company

Present Owner: Town of Greenwich, Connecticut

Present Use: Shut down September 22, 1986.

Significance: The electrification of the New Haven Rail- road was an innovative technological venture. The pioneering engineers of Westinghouse and the New Haven Railroad created the first long distance railroad electric transmission system in the United States. The Cos Cob power plant supplied the system with single phase alternating current at 25 cycles and 11,000 volts. It was a successful trailblazing effort that set the standard for American railroads.

Project Information: This documentation was initiated May 24, 1993 in accordance with the Memorandum of Agreement by the Town of Greenwich as a mitigating measure prior to adaptive reuse or demolition of the site.

Historian: Robert C. Stewart, August 1993

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The field work, measured drawings, historical reports, and photographs were prepared under the direction of Eric N. DeLony, Chief of HAER, and project leader. The recording team consisted of Robert W. Grzywacz, Architect, New Haven, CT, Team Supervisor, Dale O. Waldron Jr., Architectural Technician, Preston, CT, Thomas Cirillo, Architectural Technician, Brooklyn, NY, and Robert C. Stewart, Historical Archaeologist, West Suffield, CT. HAER photographer Jet Lowe was responsible for large format photography.

Others who have contributed their time, advice, documents

and help were: Albert Brecken (Electrician); Mary Beth Demma (CONNDOT); Wayne Drummond (New Haven Railroad Historical Technical Association); Michelle Fuller (Greenwich Administrative Services); Effie Gianos (Public Works Department); David Jacobs (Structural Engineer, Metro-North); Randall Jemerson (UCONNHM&A Archivist); Richard Holleran (Representative Town Meeting); Cece Kirkorian (Historical Perspectives); Sam Marullo (Cos Cob coal operations); Roger Nichols (Maintenance & Repair, Metro-North); David Peters (Railroad Historian); Susan Richardson (Greenwich Historical Society); Gertrude Riska (Local Historian); Charles Ruch (Archivist-Westinghouse); Susan Tritschler (Greenwich Historical Society).

INTRODUCTION:

In 1904 The New York, New Haven & Hartford Railroad decided to electrify its line from Stamford, Connecticut, to Woodlawn, New York. At Woodlawn, New Haven trains would continue to New York City over the electrified lines of the New York Central, a combined total of 33 miles. This was the first trunk-line electrification in the United States. Electricity for the railroad was to be supplied by a separate power plant. The plant went on stream in June of 1907.¹ From 1911 to 1914 the electrification was extended 45 miles eastward to New Haven. Westward expansion included freight yards and the New Haven's Harlem River Branch from New Rochelle to the Harlem River.² The railroad enlarged the original plant between 1911 and 1912 to provide additional power for the expansion.

Westinghouse, Church, Kerr & Company constructed the original plant between 1905 and 1907 at an estimated cost of \$1,130,000 (~~67-111-1111~~). Original generator capacity was 12,330 kw. It was the first powerhouse specifically built for a railroad and is considered a major engineering achievement by historians of technology.³ At the peak of its operational lifetime during World War II, the plant was producing 500,000 kilowatt-hours per day.⁴

The power plant is on the Mianus River at Cos Cob, a section of Greenwich, Connecticut about 25 miles northeast of New York

City. It was an ideal location for a coal-fired power plant. Fuel could be delivered by barge or by rail. The site had ample supplies of boiler feed and cooling water available and it was centrally located in the area where its power would be efficiently distributed when the plant was complete. By chance, the plant site is in a prime residential area, a factor that influenced its early architectural treatment. In later years building modifications required by changing load requirements and technology obliterated much of the original Spanish-mission styling. Today's public is aware of the benefits of clean air; legislation exists to combat industrial emissions. The plant's contribution to air pollution was obvious in its residential location and played a part in the plant's abandonment.

Over its eighty-year lifetime, the Cos Cob plant provided most of the electric power for the New York, New Haven & Hartford railroad. The facility was a major link in the transportation infrastructure that supports business, industry and commerce near New York City. During the early years it was in the vanguard of electrical power generation and transmission technology. On this site engineers from Westinghouse and the New Haven Railroad developed, tested, and set the standards for the electrification of American railroads in the first decade of the twentieth century.

It is the primary purpose of this project to record the physical remains of the Cos Cob power plant. Sources include

original plant layout drawings, maps, archival photographs, oral histories, trade journals, instruction manuals and texts. These sources helped interpret the facility as it was when it was a functioning plant supplying the power to move thousands of commuters daily. A series of footnotes gives details pertaining to the historical and technical context of the Cos Cob plant.

The story of Cos Cob's power plant is intertwined with the history of electricity, transportation and their influence on American life at the turn-of-the-century. To understand not only how the plant worked but where the advancements developed at Cos Cob fit into the historical context of electrical and railroad technology, this work includes a summary of the alternating versus direct current controversy in Appendix A.

The development of the electric lamp and practical electric motors during the latter decades of the nineteenth century changed work patterns forever. The availability of economical electric light extended the working day and improved productivity. Electric motors simplified supplying power to machines and made operations more efficient. Inexpensive transportation on electrified street railways enabled better-paid, skilled workers to live in pleasant residential areas away from factory districts. The move to suburbia was underway--it has been a characteristic of American life ever since--aided by inexpensive and abundant energy.

In the last decades of the nineteenth century, electrical

systems technology was in a state of turmoil. Between 1886 and 1895 proponents of alternating-current and direct-current systems fought to have one system or the other adopted as the standard. Thomas Edison championed his direct-current (DC) system.¹ It was a poor choice for transmission of power over any but the shortest distances. With equal vigor, George Westinghouse proposed an alternating-current (AC) system that overcame the transmission

¹ Direct current (DC) is a system in which one conductor is always negative, while the second conductor is always positive. Direct current generators consist of stationary field magnets and a rotating armature with a power take-off device called a commutator. The coils of wire in the rotating armature pass alternately under the north and south poles of the field magnets; the electric field generated is thus alternating. But the armature coils are connected through a switching device, moving contacts called a commutator, that switches the alternating output back and forth so that it is always unidirectional. Since all of the current generated must pass through the commutator, heavy wiring and contacts (brushes) must be used to pick up the power off of the commutator.

In alternating current, the conductors change positive and negative polarity. The rate at which the polarity is reversed is called its frequency and expressed in cycles or hertz. Alternating current generators are built with rotating fields and stationary armatures. The only moving contacts feed low voltage excitation current to the field coils. Within the generator the direction of current reverses twice during each rotation of the field.

The number of times alternating current makes a double reversal of direction per second is defined as the frequency of the current. Frequency is controlled by the generator. At the time Cos Cob station was built, optimum operating frequency for large motors was determined to be 15 cycles per second with 25 cycles per second considered an acceptable compromise. Subsequent technology allowed the design of powerful traction motors which would work well at 60 cycles per second. In the United States the standard frequency is 60 cycles per second or 60 hertz, abbreviated Hz.

loss problem. Unfortunately, Westinghouse lacked the practical alternating-current motors, metering devices and transformers needed to use this source of power.

There was, however, great interest throughout the country in electrical power. New Haven management had been experimenting with electric transit systems since 1895. Electrification of most New Haven lines was a long-term objective. A tragedy in 1902 quickened the pursuit of that goal. On January 8, a wreck in a smoke-filled tunnel leading into the original Grand Central Station killed seventeen people. The disaster resulted in legislation banning steam trains from New York City. This accident was significant in the series of events that triggered large-scale electrification and the construction of Cos Cob. Westinghouse and New Haven engineers designed, built and operated the Cos Cob plant, but it was obvious from the start that some machines and systems didn't work as planned.

The technical history of the power plant and how its systems were developed and made to work is the essence of this project. Some difficulties faced the recording staff because most of the original equipment was scrapped. Some secondary machinery dating from the 1907 plant was extant but the bulk of surviving machinery dated between 1924 and 1945. A large portion of the structure dated from the original construction, but modifications and additions hid the original architectural treatment.

This report was organized to detail the changes in plant

operation and equipment over its eighty years of service. The documentation team identified and described changes in coal-handling, steam and electrical generation/transmission chronologically.

The site is one of great significance in the history of electrical technology and the development of railroad transportation. The records show that early electrification of the New Haven line did not go smoothly. Problems the engineers did not fully understand delayed conversion and efficient operation. The history of the Cos Cob power plant is a story of the perseverance of creative engineers who designed and developed systems that evolved into a reliable transportation network. More than that, it is an account involving workers and supervisors who kept the plant going during the New Haven's bankruptcies and periods of mismanagement. The records tell of the workers who mastered Cos Cob's equipment and ran a plant that operated continuously for seventy-nine years. There are tales of determined men who doggedly kept the plant operating when the railroad was bankrupt and maintenance budgets were minuscule, often endangering their personal well-being in the process.

LOCATION OF COS COB:

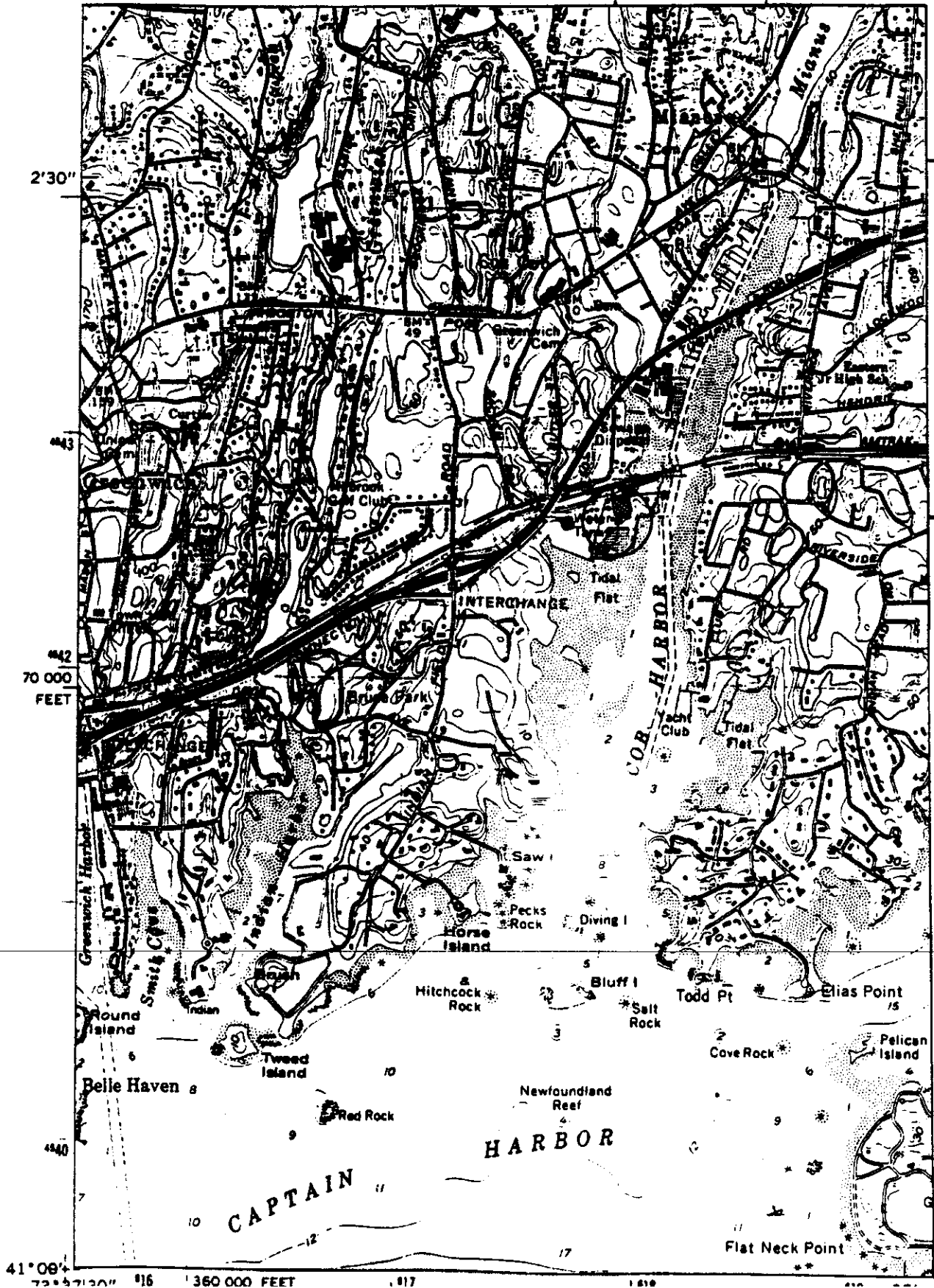
The northern boundary of the property as conveyed to the Town of Greenwich is parallel to the southernmost track of the

Metro-North Commuter railroad right-of-way and currently about twenty feet *inside* the north-facing facade of the power plant. The eastern boundary of the property is defined by the Mianus River shoreline. To the south and west, the periphery of the site follows fence lines of an electrical substation and utility rights-of-way associated with a high-tension power line. The property retained by the State of Connecticut includes the manager's office and control room of the plant. The Town's access to the property extends through the east and west boiler rooms. The legal property description is located in the Greenwich Land Records, volume 1959, page 80ff. The UTM coordinates below reflect the boundaries of the property conveyed to the Town of Greenwich.

<u>UTM Coordinates:</u>	Zone	Easting	Northing
A	18	618050	4542830
B	18	618040	4542730
C	18	617950	4542710
D	18	617940	4542580
E	18	617840	4542530
F	18	617770	4542520
G	18	617820	4542780

Quad: Stamford, Connecticut 1:24,000

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THE NEW HAVEN RAILROAD - IN CONTEXT:

During the period Cos Cob was built, the New Haven Railroad was a huge holding company, one of the most powerful and richest in America. Its holdings included almost 10,000 miles of transportation systems, ranging from the coal fields of eastern Pennsylvania to Lake Ontario. The New Haven was also engaged in maritime ventures extending from Canada to the Gulf of Mexico.

In 1909 the railroad's total capitalization was approximately \$800,000,000 and it had about 125,000 employees. The railroad exercised extraordinary political power in Connecticut, Massachusetts and Rhode Island, and was known as southern New England's "invisible government."

In 1903 the financial community considered the New York, New Haven and Hartford Railroad a prime investment. The railroad annually paid 80 percent dividends since its founding in 1872. Its stock reached a high of \$216 per share in 1904; savings banks held the stock as a secure, conservative investment.² Widow's and orphan's trusts were based on New Haven stock. The railroad was capitalized at \$93 million, of which only \$14 million was debt.

J. P. Morgan and William Rockefeller controlled the railroad

² In 1914 mismanagement caused the stock to drop to \$49. During the days before the market crash in 1929 it had recovered to \$132 1/2. In 1942 it could be bought for 25 cents a share and was finally declared valueless and replaced in the reorganization of 1947.

during the years Cos Cob was built and expanded. Charles Sanger Mellen was the president of the company.³ During the ten years from 1903 to 1913, under the Morgan interests, capitalization increased by \$324 million. A considerable amount of this was "watered" stock and almost two-thirds of the new capital went for activities that had only the most tenuous connection with the railroad. The Morgan interests used the New Haven treasury as a source of cash for rewarding inside investors and contractors. Over the years the financiers bilked stockholders out of 200 million dollars.⁵

Yet, in part because of the schemes of Wall Street during those years, there was an abundance of money floating around. The railroad was on its way to becoming a "transportation octopus." It operated rail, trolley lines, interurban light rail, steamships and later truck freight and bus lines. The same monopolistic mentality prevailed even when the railroad was bankrupt. In 1938 even an embryonic airline came under its

³ In 1914 the railroad was under investigation. Its president, Charles S. Mellen had been indicted on June 30, 1914 for allegedly bilking the stockholders out of \$65,871,299. A number of critical corporate files disappeared. Some were destroyed by fire of uncertain origin. A curious routing of a box car which was carrying the entire records of one subsidiary, dispatched them to Canada. They could not be returned because of customs regulations.

Louis D. Brandeis prosecuted Mellen. Brandeis became a Justice of the Supreme Court partly on the basis of his unflagging prosecution of New Haven management (Weller, 1969:3).

control.⁴

Regardless of the motives of its financial backers, the New Haven had the capital, dynamism and drive to try new ventures. It was endowed with creative engineering talent eager to work on the advanced technology of the period--electrification. Morgan, familiar with Edison's and Westinghouse's activities, saw electricity as a new and profitable technology. He sanctioned the capital investment in electrification. Besides, Morgan, a Hartford native, had a soft spot in his heart for the railroad. It had strong ties to his home town and he always called it "The Hartford." More to the point, it was always a source of ready cash to be "borrowed" for Morgan's other enterprises.

⁴ The airline was a joint venture with TWA (Transcontinental and Western Airlines) to maintain market share of first-class service between Boston and New York while the Shore Line was being repaired after the hurricane of 1938. It was to be known as TWA New England or TWANE. One still took the "TWANE" to New York. (Weller, 150-154 passim.).

DEVELOPMENT OF RAILROAD ELECTRIFICATION:

The notion of using electricity to power a railroad is almost as old as the history of railroading. Frank J. Sprague, a prominent engineer associated with the electrification of the New York Central, researched the origins of the electric railroad.⁵ Sprague claimed that a blacksmith in Brandon, Vermont, by the name of Thomas Davenport, built the first model electric railroad in 1834.⁶ While those origins may be somewhat fanciful, Sprague did document several early railway electrification projects.

Sprague found that an electric locomotive ran on the Edinburgh-Glasgow railway in 1838. Robert Davidson of Aberdeen, Scotland, was its builder. Reportedly, it achieved a speed of four miles per hour. Other experiments followed during the mid-nineteenth century. In 1840 Henry Pinkus patented the use of rails for conducting current to an electric locomotive. Moses Farmer of Dover, New Hampshire operated an experimental electric railroad car in 1847. And in 1850, Thomas Hall developed an

⁵ Frank Julian Sprague was born in 1857 in Milford, Connecticut. He became an electrical engineer and worked with Edison developing equipment for an experimental electric locomotive in 1885. He built the first large scale trolley system in the United States at Richmond, Virginia in 1888. Sprague also developed a multiple unit (mu) control system which enabled individual electric cars to be combined into trains of any length and yet be controlled from a single master unit. He had a long and distinguished career in the electric industry and was known as "the Father of Electric Transportation." (Uher 1988:11).

automatically-reversing car that operated on battery power.⁷

Around 1850 Professor Page of the Smithsonian obtained a grant from Congress and built a car with a double solenoid motor.⁶ It had a reciprocating plunger and fly wheel that gave its running gear a motion similar to a steam engine. It received power from one hundred "Grove elements" and had its first run on April 29, 1851 using the right-of-way of a railroad running from Washington to Bladensburg, Maryland.⁷ Reportedly it attained "a fair rate of speed."⁸

One of the major motives that drove electrification was that steam locomotives were power-limited. The steam locomotive had to haul its energy-conversion machinery as well as the train. E.H. McHenry, Vice President of the New Haven, explained;

In steam service, weight and speed of the trains are limited by the horse-power capacity of the locomotive, few locomotives can generate sufficient steam to utilize their full cylinder tractive power in excess of 12 mph. Increase in speed can only be obtained by sacrificing train tonnage correspondingly.⁹

Electric traction would allow high speeds without sacrificing commercial tonnage, because with unlimited power available, the maximum drawbar pull permitted by motor design

⁶ Solenoid: A hollow coil of wire in the form of a cylinder. When a current is applied through the wire the coil becomes a magnet. Any magnetic material brought adjacent to the open center core of the coil will then be drawn inside the hollow core of the coil, coming to rest when centered within the coil. Solenoids may be considered a form of linear motor.

⁷ The Grove elements may have been a primitive fuel cell.

could be maintained at all speeds.

A primary advance in nineteenth century technology was the expanding applications for electricity. But the key invention that made the electric railroads possible was the dynamo, also known as a generator. Prior to 1870 the primary use of electricity was in the electric telegraph. The batteries then available were capable of supplying the low currents needed to operate telegraph systems. However, they were not practical for supplying large amounts of power over extended periods of time.

The simple generators of the period relied on permanent magnets to create their magnetic field.⁸ In 1866 Werner von Siemens and Johann Halske manufactured a dynamo in which the magnets were replaced by much more powerful electromagnets.¹⁰ The electricity passing through the electromagnets was called the "exciter" current. By 1878 alternating-current generators had been developed independently by Gramme and Fontaine in France, and Siemens in Germany. These improvements enabled the generation of sufficient electrical energy to run powerful traction motors.

⁸ Hans Christian Oersted, a Danish physicist, accidentally discovered the link between electricity and magnetism in 1819. In 1824, William Sturgeon, a science lecturer at the British Royal Military Academy, London, discovered that non-magnetized soft iron could be turned into a temporary magnet by forming a coil of insulated wire around it. When a current was passed through the wire, the iron core became magnetized. The 'electromagnet' formed the basis for a machine which could generate electricity cheaply and efficiently; the dynamo or generator (Desmond, 1819).

Using this technology, Siemens and Halske set up a temporary electric streetcar line for the Berlin Industrial Exhibition in 1879 to demonstrate the practical applications of electric transport.¹¹ They also built the first electric mine railway at the Zauckeroda coal mine in Saxony during 1882.¹²

As this evidence indicates, the concept of an electric railroad had been around for many years when the City of Richmond, Virginia, under Frank Sprague's direction, built the nation's first electric trolley system in 1888. The line was successful, and with the replacement of the horse-drawn cars, the city streets became cleaner. Posters proclaimed that "Sprague has set the mule free! The long-haired mule shall no longer adorn our streets!"¹³ Part of the jubilation was due to the elimination of a major source of odor and manure from the city streets.

Once the technology was available, the public increasingly demanded a transportation system that didn't rely on animal power with its need to care for thousands of horses and clean up tons of manure. To satisfy this need, the electrically propelled vehicle was developed rapidly during the 1880s and 1890s. City transit lines and interurban routes were electrified, yet common carrier/mainline railroads ran on steam power. In 1895 the Baltimore and Ohio Railroad was close to achieving electric operation through a tunnel under Howard Street in central

Baltimore.⁹ But the idea of operating a United States' mainline railroad without steam power was untested prior to June 3, 1895.

On that date, the New York New Haven & Hartford opened an electrified short branch line between Nantasket Beach and Pemberton, Massachusetts. The section of track was 4.95 miles long. It was the first electrification of a steam road in America and slightly antedates the electrification of the Baltimore and Ohio tunnel.¹⁴ During the waning years of the nineteenth century, the New Haven electrified three lines totaling 33 miles using an overhead trolley. Several other lines totaling 39-1/2 miles were designed for third-rail transmission.¹⁵

Experience showed the trolley-pole method of current collection was not satisfactory. Trolley wire could get electricity to a moving vehicle on a slower route, but at high speeds the poles left the wire. The engineers tried a third-rail for power transmission. On July 26, 1896, the Nantasket Beach experiment was extended a half mile to East Weymouth, using a

⁹ The Baltimore & Ohio Railroad reached the vicinity of New York City in 1889. Traffic through its eastern Maryland facilities expanded and created a serious operational bottleneck in Baltimore. At the time the railroad used car floats to ferry trains across the Patapsco River, a system that created additional expense and delays. To bypass the float operation, a new line, tunneling under central Baltimore, was built. A shallow tunnel would have solved the railroad's problem but venting it would have caused distress to abutting property owners. Electrification, using a 600 volt direct current system was the preferred solution (Condit, 1351). The first trial of the system was on June 27, 1895; the first train ran on July 1, 1895. (Greenhill 1985:192).

third-rail centrally located between the tracks.

All lines were operated using 500 volts DC. The third-rail had no protective shielding of any kind. Consequently there were many accidents and electrocutions of small animals, livestock and an occasional person. The Connecticut Superior Court compelled the railroad to abandon all third-rail service in a decree dated June 13, 1906.¹⁰

During this period of experimentation, the New Haven regarded electric operation as being cost effective in areas of dense traffic. The 1895 NYNH&H Annual Report to the Stockholders says:

The experiment has demonstrated that power generated in a stationary plant, and transmitted by electrical energy can be successfully used in the operation of a standard railroad. The current expenses for fuel indicate that this is economically obtained.¹⁶

The New Haven railroad continued to electrify its lines during this period. Service was provided to single cars as well as relatively heavy trains. Prior to 1901 the lines from Hartford to New Britain, Berlin, Bristol, Plainville and Forestville, as well as Stamford and New Canaan, Connecticut were electrified. Other towns in Rhode Island, Massachusetts and Connecticut were electrified after the turn of the century. The railroad employed

¹⁰ The original third rail was shaped like an inverted "V" and weighed 98 lbs to the yard. It was fixed to insulators centered between the two running rails with its apex raised about an inch above them. Each car had a pickup shoe mounted on each truck in such a way that the shoe rode on the apex surface of the inverted "V". The third rail had breaks at switches and crossings.

600 volt direct-current for powering its systems and accumulated substantial operating experience during this period.¹⁷ But later financial results were not up to the optimistic forecast of the 1895 stockholders' report and some of these lines were abandoned or returned to steam operation.¹⁸

Analyses at the time showed that considerable savings in fuel, engine repairs and other operating expenses could be achieved by "going electric," but the records show it wasn't a simple decision. In 1907 E.H. McHenry declared:

It is altogether improbable that the direct saving resulting from the simple substitution of electric for steam power will be sufficient to justify the additional investment and financial risk.¹⁹

It wasn't as elementary as just constructing new lines, because a great amount of invested capital had to be sacrificed. The transition stage from electric to steam was difficult and expensive. The change affected train lighting, heating, telegraph and telephone service, signaling, and track maintenance. When switching over, both temporary and permanent provisions had to be made. E.H. McHenry went on to say:

The simultaneous maintenance of facilities and working forces for both steam and electric service within the same limits will rarely be profitable, for the reason that a large proportion of expenses incident to both kinds of service is retained, without realizing the full economy of either.--To secure the fullest economy it is necessary to at least extend the new service over the whole length of the existing engine district, and to include both passenger and freight trains."²⁰

Indeed, the railroad's plan was to extend electrification

all the way to Boston and eliminate the costs of maintaining both steam and electric operations. In part due to financial mismanagement and expansion into a wide variety of transportation schemes, the extension was not built.²¹

While the New Haven was electrifying some of its lines in southern New England, the event which precipitated electrification within New York City was taking shape. The old Grand Central terminal was built between 1869 and 1871 at Forty-second Street and Park Avenue. The tracks approached from the north along the center of Park Avenue in an open cut which started at Ninety-sixth Street. The cut was roofed over and ventilated with air shafts covered by steel grilles. These openings were an annoying source of soot, smoke and steam to pedestrians and abutting property owners. Additionally, passenger traffic growth, the narrow access tunnel and dead-end feature of the old Grand Central terminal imposed capacity limitations on the station. By 1891 the terminal had reached its functional limit.²² The New York Central commissioned a study which recommended construction of an electrified underground terminal to replace the original Grand Central Station. Their report was published in August, 1901.

Signals in the Central's Park Avenue tunnel were routinely obscured by steam and smoke. On January 8, 1902, the engineer on an inbound New York Central locomotive failed to see a red signal and crashed into the rear of another train, killing seventeen

people. This unfortunate accident provoked public outrage and accelerated electrification. In response to public pressure, the New York State legislature passed a law in May of 1903 forbidding the use of steam locomotives within the city limits, requiring trains to be powered by some means other than combustion on the train itself.¹¹ The ban was to take effect on July 1, 1908. The law was directed at the New York Central and the Long Island railroad. At the time the New Haven terminal was north of the Harlem River, outside the proscribed area. The New Haven was not directly affected.²³

The New York Central electrified the 13 miles of its line between Grand Central Terminal and Woodlawn, N.Y. using low-voltage direct-current, picked up by the locomotives from a side-mounted third-rail. Electricity was generated as 11,000 volt, three-phase alternating-current that was transmitted to substations located about five miles apart along the track. At these substations it was converted to the 660-volt direct-current supplied to the third-rail. Power was taken off the third-rail by a contact shoe that rode on the underside of the locomotive. The top and sides of the third-rail were covered to prevent snow accumulation from interfering with power transfer and to add a degree of safety. New York Central's first public run was made

¹¹ The City of Chicago had a similar accident and a legislative reaction. They solved the traction problem by using battery-operated locomotives.

under electric power in 1906.²⁴

Although the New Haven was not compelled to electrify, its management wanted to obtain direct access to a terminal in Manhattan and had been planning electrification for some time.¹² If the electrification was to be limited to New York, then NYNH&H would have gone along with DC motors and a third-rail system. But NYNH&H was interested in electrifying the whole system and not just in having access to Grand Central. In 1905, Charles S. Mellen, New Haven's president, announced that the railroad would electrify using a single-phase alternating-current system and an overhead trolley distribution system. The system selected combined efficiency, flexibility, simplicity and lowest first cost. The New Haven System was a network of lines, and transmission problems had to be solved on an area wide basis rather than for linear distances. An area served increases as the square of the radius of transmission from the generating center,

¹² The New Haven did not gain direct access to the west and south through New York City until after the Hell Gate Bridge route was opened in 1918. The route branched off from the New Haven main line just west of New Rochelle station. It paralleled the shore past West Farms to Oak Point, crossed Hell Gate Bridge to Sunnyside Junction on Long Island. At Sunnyside the line turned west and crossed under the East River through the Pennsylvania Railroad tunnels. The new route facilitated passenger service between Boston and Washington.

The Hell Gate Bridge was designed by Gustav Lindenthal. It spans 977' from center-to-center of its pins. It cost \$ 12 million and is the longest and heaviest steel arch ever built, requiring 80,000 tons of high carbon steel (DeLony, 120). The top of the bridge is 305' above mean low water with a clearance of 140'. It rests on two steel shoes weighing 250 tons each.

so high-voltage transmission was attractive for economic reasons.²⁵ The New Haven Engineering Department had given the selection of a system careful study. Nevertheless, the announcement astonished the engineering community.¹³ At the time alternating-current locomotives did not exist in the United States and there were no large-scale alternating-current railroad transmission systems.²⁶ In addition, the New Haven's locomotives would also be required to operate on the New York Central's third-rail DC system from Woodlawn to gain access to Grand

¹³ Both three-phase and single-phase high voltage transmission were considered. But tests showed the efficiency of three-phase between power house bus bars and engine collector shoes was 75 percent while it was 95 percent for the single-phase system. The flexibility of three-phase was also handicapped by the limited radius of the secondary low tension distribution which required substations at frequent intervals.

The third rail itself imposes limitations. Aside from the electrocution hazards which the New Haven encountered in its early third rail experiments, there were mechanical limitations. The height of the rail and its position had to be rigidly maintained. Continuity of the third rail was interrupted at switches and crossings. This caused interruptions in the locomotive power supply. These factors worked against a third rail system.

The designated single phase overhead system did not require substations or secondary circuits. The line power losses were minimized by transmitting 11,000 volt AC. Later, the system was improved and losses cut further by transmitting 22,000 volts AC and using the rails as a neutral conductor.

In the selected system, the overhead trolley was continuous and its position could vary within limits of 8' vertically and 4' horizontally without losing contact with the pantagraph frames (McHenry, 177).

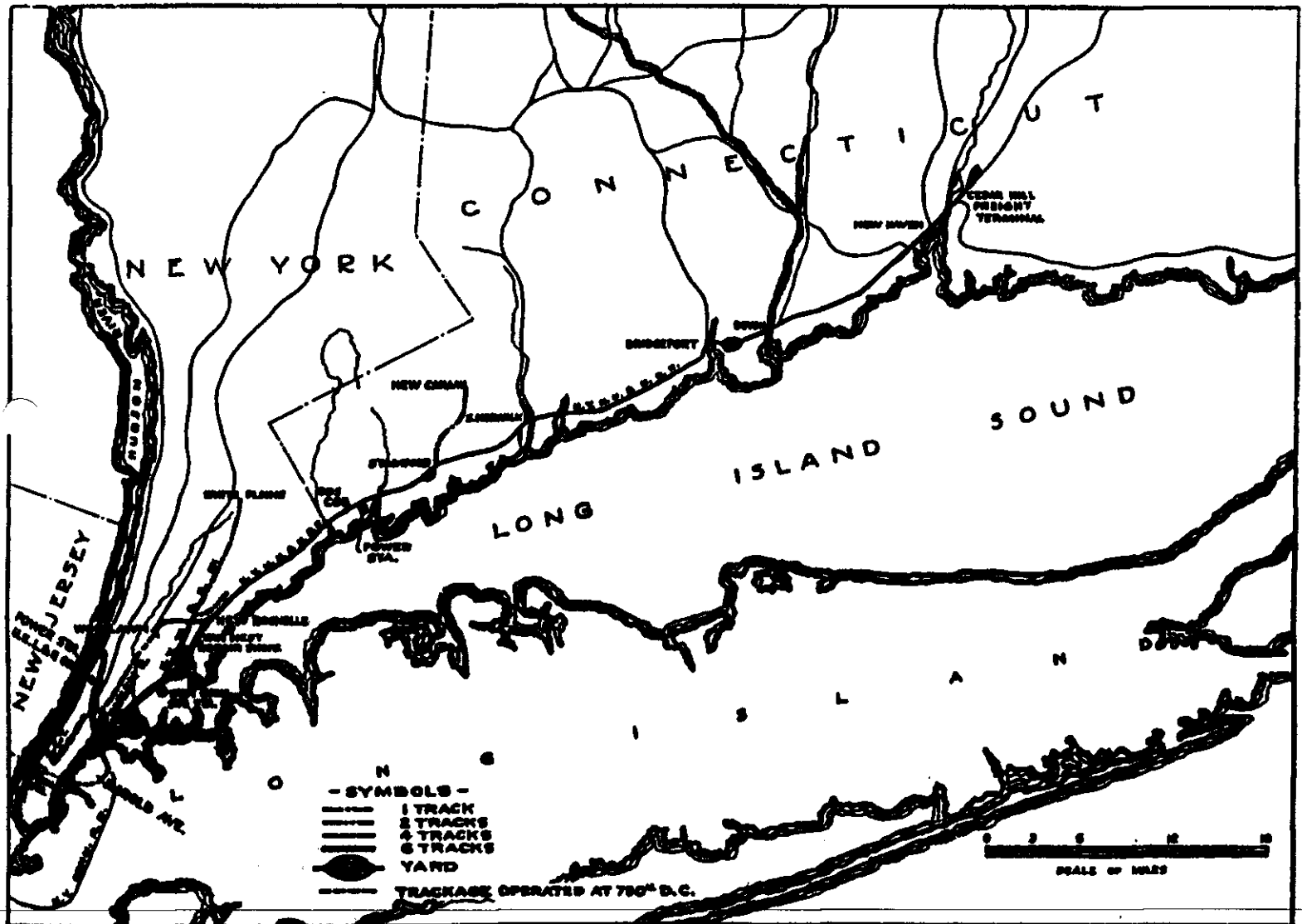
Central station.¹⁴ Locomotives would need some sort of dual power system with the additional capability of receiving power from a third-rail or overhead trolley wire.

The New Haven's management planned to electrify as far east as New Haven, 66 miles from Woodlawn, using an overhead transmission system (figure 1). A single-phase overhead system required no substations and its trolley position could vary. If successful, 317 more miles of line would ultimately be electrified. Earlier experience with the electrification of short sections of the system gave evidence that over such a distance the use of high voltage alternating-current for both transmission and operation would be more economical.

In the early days of electric use, a major scientific dispute had erupted over the standards for electric transmission systems. By 1905 the technical dispute over direct and alternating-current had been settled (see Appendix A). While alternating-current was shown theoretically to be superior for most applications, it had not been around long enough to be considered a mature technology.

¹⁴ Construction on Grand Central started in 1903, and completed in 1913. Passenger traffic was handled without interruption during construction. The terminal handled 161 New Haven and 243 New York Central trains daily. The New Haven handled 11,400,000 passengers in 1916 and 16,4000,000 in 1920.

The construction of the terminal reclaimed 40 acres of air rights for buildings. There are two levels of tracks with over 32 miles of track within the terminal (UCONNHM&A-IFIP, 1).



Map of New Haven Electrification Showing Number of Tracks and Location of Yards, Substations and Power Plant

Figure 1: Westinghouse Electric & Manufacturing Company, 1924

The decision to go with an alternating-current system at 11,000 volts and 25 cycles was based on sound scientific reasons. The determination of the most economical and desirable frequency and voltage of the transmission system involved the consideration of many factors. The choice of frequency was limited to 15 cycles or 25 cycles. The lower frequency afforded a material reduction in weight, size and cost of motors, a reduction in conductor losses and induction disturbances, together with an increase in power factor of the motors. However, adoption of 15 cycles would have materially decreased the commercial value of the system as a whole; other incidental railroad uses would be restricted or prevented.

New Haven's standard frequency in use for its streetcar operations was 25 cycles, it had power stations generating 25 cycles for trolley operations and its shops were equipped with 25-cycle motors. Adopting 15 cycles would have resulted in the abandonment of a large amount of standard apparatus or installation of expensive frequency converters.¹⁵

¹⁵ Current frequencies for railway electrification were evidently a source of contention. Prominent railway electrical engineers took positions on the issue:

B.G. Lamme "--it is my opinion--that this compromise is considerably below 25 cycles and should be about 15 cycles."

N.W. Storer "Everytime a single phase motor is designed for heavy work, the question of frequency arises, and it always works out much better for 15 cycles."

Also, New York Central had adopted 25-cycle generators. The management considered a change from 25 to 15 cycles the "equivalent to a break in gauge" and it was decided that "the practical commercial value of the higher frequency outweighed the theoretical merits of the lower one."²⁷

Then the engineers considered the voltage to be generated. One proposed system required generators to be designed to the highest practical contemporary limit, 22,000 volts AC. This would maximize transmission range at the expense of constructing voltage-reducing transformer substations along the line. However, the engineers found that system capital cost could be reduced by cutting the system voltage to 11,000 volts AC. This simplified the electrical equipment needed on board the locomotives and eliminated the need for intermediate substations. Operating cost was decreased, and electrical efficiency increased. Current collector design (the pantagraph system) was also simplified.²⁸

The 11,000-volt alternating-current scheme also posed compatibility problems with the New York Central's third-rail, 600 volt direct-current system. Mellen committed the engineering

Wm. McClellan "--15 cycles is better than 25. I for one, after a very careful examination of every argument, feel sure that nothing stands in the way of the standardization of this frequency."

Despite the unanimity, 25 cycles became the standard. The railroads and industry had a large investment in 25 cycle motors in maintenance and repair facilities. The realities of capital investment triumphed over electrical theory (Uher 1988:18).

staff to years of heavy responsibility and labor to solve these problems. Professional reputations were at stake and so were millions of dollars in capital investment. The stakes were considerable--success would provide the solution to the problem of powering heavy trains at high speeds over great distances with electricity.²⁹ The system, completed in 1907, set the standard for power characteristics in American Railroad electrification: single-phase alternating-current at 11,000 volts and 25 cycles.

The design was both bold and risky. It involved concepts that were unproven outside a laboratory, and required equipment untried in large scale railroad operations. The proposal was a departure from the accepted standards and proven components of the period.

Although the engineers were on the brink of an incredible technical adventure, the railroad financial people had their eye on the budget. The engineers were not given free access to the company coffers. E.H. McHenry commented:

...the natural prejudice of the stockholder in favor of the continued maintenance of dividends must be respected, and the technical expert too frequently neglects this in his scientific ardor.³⁰

THE COS COB POWER PLANT:

In 1905 the low frequency 25-cycle power necessary to electrify the NYNH&H railroad was not available from commercial

sources--the company was obliged to design and build its own plant independent of the public utilities.³¹ The railroad, like much of American industry at the time, had an inclination for vertical integration. The New Haven tended to do everything from heavy construction and maintenance to timetable printing within its own organization. Building and owning its own power plant was in keeping with this practice. The railroads did not foresee a time when it would be cost effective to adapt their systems to commercial power.³²

The railroad settled on Cos Cob, Connecticut as the site for its power plant. From an engineering and cost standpoint it was an ideal location. The site was reachable by both water and rail transport. Coal could be delivered to the plant by either means. Unlimited quantities of brackish water were available from the Mianus River for cooling and condensing. Pure, fresh water for boiler feed was available for making steam.^p In addition, the

^p Feed water must be pure to (1) eliminate mineral deposits, primarily calcium, from sealing over boiler tube surfaces and causing them to burn, (2) prevent corrosion and pitting and (3) eliminate any tendency to form foam in the system. Contamination can consist of (1) floating or suspended solids, (2) Dissolved solids or hardness, (3) dissolved gases, (4) acidity or alkalinity, (5) liquids or greases.

Water treatment included removal of air (oxygen) by preheating. pH (degree of acidity or alkalinity) was optimized. Dissolved calcium salts would form boiler scale and had to be removed. Until 1935, the only products available for exchanging the calcium and magnesium ions in the water for non-scale forming sodium ions were natural or synthetic zeolites. Zeolites are double silicates capable of undergoing reversible exchange reactions. The zeolites could, under some conditions, add scale producing silica

municipal water supply of the Town of Greenwich was tied into the boiler feedwater system and could be used to back-up or supplement the river supply.³³ Cos Cob was also favorably located to distribute power.

The plant was situated in a residential neighborhood located on a beautiful harbor. The architectural treatment and red-tile roof harmonized with the physical surroundings. Induced draft fans on the boilers allowed for a low and relatively unobtrusive smokestack. A Roman arch effect on the feedwater reservoir obscured its purpose and lent a classical touch to the site. The site was landscaped with trees and shrubs to screen industrial components. The coal dock, connecting cable railway to the plant and power transmission lines were the only major outward indications that the Cos Cob building was an industrial site (see photograph CT-142-A-8).

Walls of the plant (original dimensions 248' x 112') were plain-faced concrete blocks made on site with crushed gneiss aggregate excavated on the site. Specifications called for foundation walls below the water table and machinery footings to be monolithic concrete. All interior columns were constructed of concrete block, except for the steel columns in the boiler room.

to the feed water and they were displaced by organic exchange resins. Cos Cob adopted the organic resin ion-exchange system in 1977 (Perry, 915, 1648).

Steel trusses, carried on interior pilasters, were specified for roof support. The roof was composed of reinforced light-weight cinder concrete faced with red Ludowici tile.³⁴ A monitor roof was built to provide light and ventilation to the boiler room and turbine hall. The turbine hall was 60' wide X 112' long X 39' high to the bottom of the roof trusses. The original boiler room was 160' long and 110' wide. The architects gave the turbine hall an ornamental touch with a wainscoting of Faience tile carried to a height of 6'.³⁵

The architectural style of the building is Spanish-mission.³⁶ However, antecedent architectural renderings of other styles were discovered in the New Haven Railroad corporate records (figure 2). The earliest drawing was a functional design typical of early 20th century mills and factories. It featured a flat roof with large windows. As the conceptual design evolved, the building exhibited a Spanish Romanesque exterior with scrolled gables, tiled, hip roof and heavy arched windows. The third design lightened some of these elements to exemplify the Spanish California Mission style.³⁷ It is apparent that the architects spent considerable effort in designing a building which was aesthetically pleasing and would harmonize with the residential nature of the area and Cos Cob harbor (figure 3). Additions have hidden or eliminated many details of the original exterior.

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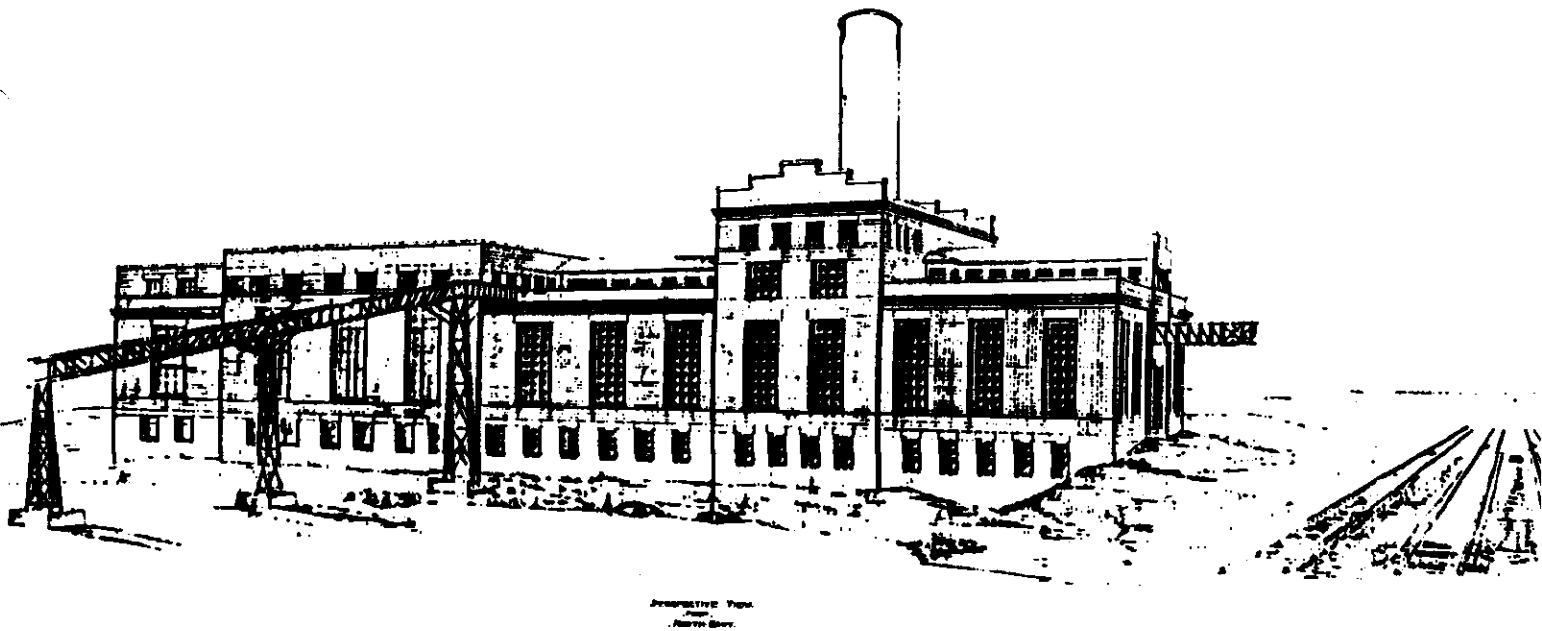


Figure 2: Proposed Cos Cob Power Plant-Industrial Style
Westinghouse, Church, Kerr & Company

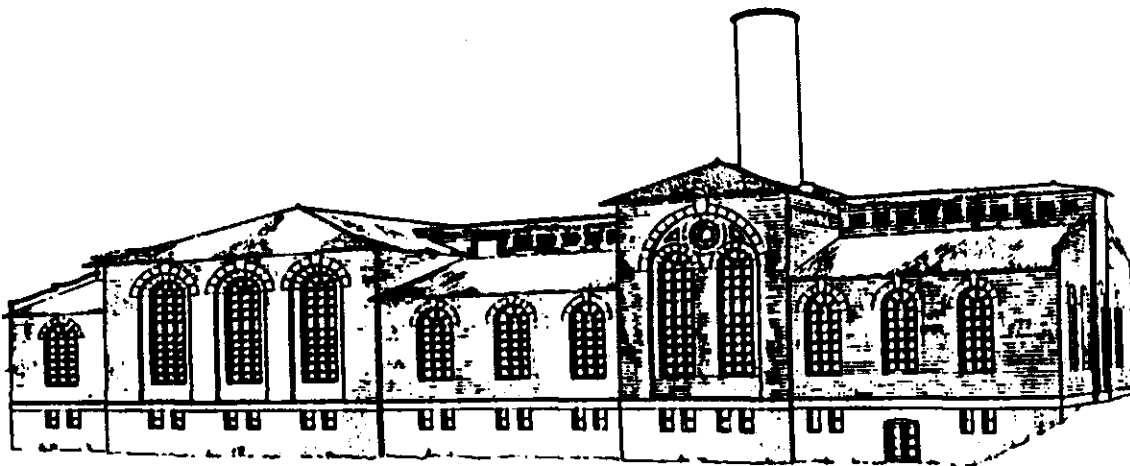


Figure 3: Spanish Mission Style-Cos Cob Power Plant
Westinghouse, Church, Kerr & Company

MAJOR BUILDINGS AND SYSTEMS:

The generation of electric power at Cos Cob was a complex process which can be more easily understood by breaking it down into constituent components and their function. Water is fundamental for both making steam and cooling. Fuel and its transport is another basic element. Boilers, turbines and generators are energy conversion devices essential to the process.⁹ Finally, an electrical distribution system is necessary to distribute the product to where it can do useful work.

There was no single electric generation scheme for the Cos Cob Power Plant. Sidney Withington, electrical engineer for the railroad, claimed there were six different electrification systems developed and tried before the system worked as planned.³⁸ For the first fifteen years, the New Haven Engineering Department and the Westinghouse engineers were engaged in what was, in many respects, an ongoing developmental project. Involved in a pioneering effort, they came up with solutions to problems, some of which worked, some of which did not. The net result of this development activity was that the plant and its systems were constantly changing.

⁹ Since the main generators at Cos Cob produced alternating current, a more accurate term to describe them is "turbo-alternators." However, in the contemporary literature reviewed for this work they were called turbo-generators. That is the term used throughout this paper.

Over the years the plant adapted to shifting technology, capital equipment investment policies, power demands, cultural changes and governmental regulations. W.S. Murray, chief engineer for the New Haven, described the effort in The Log of the New Haven Electrification. Murray claimed his paper was a "how-not-to-do-it manual" that helped other railroads achieve electrification with ease.³⁹ From 1907 until about 1924, changes were made to advance the technology and provide additional power for a growing system. After 1924 Cos Cob was less innovative, and modifications tended to be more in the nature of improvements to existing systems and replacement of obsolete or worn-out equipment.

FRESH WATER-The 1907 Boiler feed system:

Boiler feedwater could come from two sources. A small electrically powered pump house at Mianus, about one mile north of the plant, provided water that was impounded behind a crib dam. The water was delivered through a 10" main to a 600,000-gallon circular concrete tank outside the power house that remains as part of the original 1907 design. The original purpose of this tank was to supply water in the event of pump failure or a break in the main coming from Mianus. The tank is built directly on native rock. Its walls are made of concrete reinforced with a steel cable which spirals around the structure

from the foundation to its top rim. The inside is waterproofed with Hydrex felt and sealing compound which is covered by a veneer of brick for additional protection.⁴⁰

The second source of water was from the Greenwich municipal water supply. Cos Cob was originally designed to operate as a surface condensing plant, and could recycle up to 85 percent of its boiler feedwater.⁴¹ The reservoir of Greenwich municipal system had only to supply make-up and service water.

The original Mianus pumping station had two single-acting vertical triplex plunger pumps. These were operated by Westinghouse three-phase motors using current supplied from the power house.⁴¹ Water flowed from the Mianus 10" main into the external 600,000-gallon reservoir. A steam pipe kept the reservoir free of ice in the winter. From the reservoir it flowed into two 13,000- gallon feedwater tanks in the boiler room basement. These tanks also received water discharged from the hot wells of the surface condensers.⁴² With this system, most of the condensate returned to the boiler feedwater supply; little water was lost and make-up requirements were small.⁴³ From these basement tanks water was pumped through heaters and the economizers into the boilers.

A surface condenser may be compared to an automobile radiator with cold brackish (saline) water replacing air as the coolant. Exhaust steam would flow through the inside of the radiator, cold water on the outside. The steam would condense back to water, uncontaminated by the salt water used for cooling.

A continuous supply of pressurized feedwater is indispensable for safe operation of boilers. Water could also be taken from the municipal water supply through a cross connection.⁴⁴ An emergency feedwater supply system was available to take water from either source of supply and deliver it through a separate line to the boilers.⁴⁵ The system also had reserve boiler water feed pumps to back up the supply. As with all systems in the plant, back-up machinery and equipment was on standby status ready to be placed on line if it was needed.

COAL-1907 Delivery and Processing: (See Appendix D for diagrams)

The architects considered the detrimental effect of an outside coal storage pile on the aesthetics of their design and the neighborhood. Coal facilities for the original plant were unobtrusive and had only a minimum visual impact on the surrounding environment.

Sympathetic to the desires of the town, the designers allowed aesthetic concerns to override good industrial engineering practice in some instances. The first coal inventory and supply scheme wasn't very practical. It discounted the possibility of interruption in the supply stream and did not provide for adequate reserves. The need for additional on-site coal storage to assure continuous plant operation was apparent, and starting in 1910 coal-handling systems were modified several

times. These changes, while unquestionably necessary and practical, had a negative effect on the external appearance of the plant.

In the first fuel-handling system, coal was supplied by water and by rail. A tidewater tower was located on a dock at the edge of the navigable channel (CT-142-A-24). During the early years of plant operation, the tidal area between the tower and the shore was filled with fly ash from the plant and the coal dock was incorporated into the main plant site.

There was no external coal storage in the original site plan. Internal bunkers held about 350 tons. The conveying machinery could handle 400 tons in 9 hours.⁴⁶ Coal was delivered on a just-in-time basis and either used immediately or stored in inside bunkers. The coal-unloading operation was not run at night, during which time the plant operated on coal accumulated in two underfloor bunkers during the day.⁴⁷

Coal received by water was unloaded by a clam-shell bucket operating in conjunction with a steam-powered derrick. The bucket delivered the coal into a 15-ton hopper. The hopper was located 55' above the dock. The coal flowed by gravity into a coal-crusher and then into weighing cars. These steel cars were pulled by cable up a 13 percent grade through an opening in the boiler room roof. Two cable cars could be operated simultaneously by utilizing a centrally located automatic bypass.

The cable cars released the coal into hoppers which, in

turn, deposited the coal onto the lower level of dual two-tier flight conveyors which ran the length of both sides of the firing aisle (CT-142-A-26).⁴⁸ Each flight conveyor served up to eight boilers. As the coal was conveyed from the south to the north end of the boiler room, it successively filled the spouts of each boiler hopper. Any coal that passed over the spout of the last boiler in the row was discharged by a ninth spout into the bunker below the boiler room floor. The waterside unloading operation was run only during the day and the coal in the bunkers below the floor was stockpiled for night operation of the plant. These sub-floor bunkers discharged onto a bucket conveyor in a tunnel. This bucket conveyor carried the coal up to an elevated hopper. The coal was dropped from the hopper on to the upper level of the two-tier flight conveyor belt that conveyed the coal to the south end of the boiler room. A second bucket conveyor lifted the coal from this conveyor to the bunkers located above the south end of the boiler room over the firing aisle.⁴⁸ From these bunkers coal was deposited onto the lower tier of the flight conveyor, thus making a complete circuit.

Coal delivered by rail was originally dumped directly into a

⁴⁸ A flight conveyor consisted of a metal trough about 2.5' wide. Two parallel chains linked together by rigid crossbars dragged the coal along the trough. As coal was moved along the trough it was discharged at each boiler hopper through a large tube connected to an opening at the bottom of the trough.

chute that led to a crusher. Crushed coal flowed into the 350-ton bunker located under the floor at the north end of the boiler room. This was the same bin used for stockpiling coal for night operation described above. From this point, the coal followed the same path to the flight conveyors and boilers as reported under the 1907 water coal system.¹

COAL FEED TO BOILERS - Stokers in 1907:

Stokers are mechanical devices used to feed coal into the boilers." The first mechanical stokers installed at Cos Cob in 1905-1907 were Roney multiple-retort mechanical underfeed stokers.⁴⁹

BOILERS, TURBINES & GENERATORS - 1907:

¹ Specifically, coal was then conveyed by a bucket conveyor located in a tunnel beneath the bin to an elevated hopper. The coal was dropped onto the upper level of a two-tier flight conveyor belt which conveyed the coal to the south end of the boiler room. A second bucket conveyor lifted the coal from the conveyor to the bunkers located above the south end of the boiler room above the firing aisle. From these bunkers coal was deposited onto the lower tier of the flight conveyor.

" Mechanical stokers burn solid coal at efficiencies of 70 to 80 percent, feed fuel at a controllable rate, control and proportion combustion air and remove ash. The Roney stokers were of the underfeed type--fresh fuel was introduced from beneath into troughs located between inclined tuyeres which admitted forced-draft combustion air. The ram action of the feeder served to break up any caked coal. Ash was dumped out through the bottom of the boiler. (Perry 1950:1640).

Cos Cob's original steam generating equipment consisted of twelve, 525 hp. Babcock and Wilcox water-tube boilers arranged in pairs (CT-142-A-25). Boilers were equipped with superheaters and delivered steam at 200 lbs. pressure and 125 degrees superheat.^{50v} They were fired with bituminous coal. A layout of eight boilers on the east side of the room and four on the west, left room for four additional boilers to supply a future turbo-generator.⁵¹ (figure 4).

The brickwork of the boilers was entirely encased within an external sheet-iron casing to eliminate the possibility of air leakage. This construction was considered technically innovative in 1907.⁵² It was a feature especially important in an induced draft installation--air leaks increased the load on the fans and their consequent steam consumption.

^v A superheater is a heat exchanger within the boiler that adds additional heat to the steam without raising its pressure.

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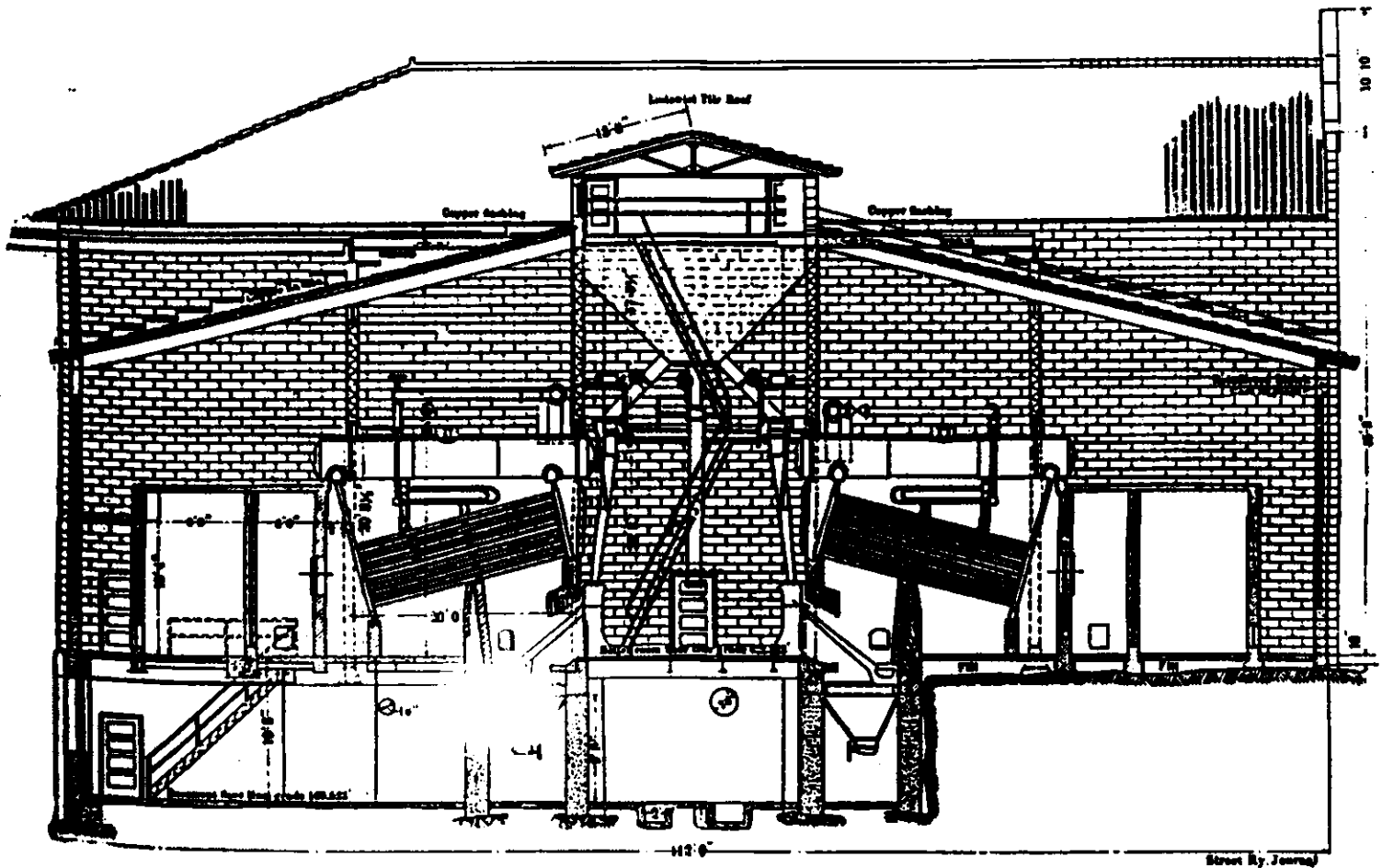


Figure 4: Section of Original Cos Cob Boiler Room, 1907
Westinghouse, Church, Kerr & Company

ECONOMIZERS-1907:

The original boiler installation was provided with three fuel economizers manufactured by Green.^w These were equipped with bypasses that allowed the operator to adjust flue gas flow to changing demand upon the boilers.⁵³

INDUCED DRAFT SYSTEM-1907:

After passing through the economizers, flue gases flowed through sheet-iron flues into a fan chamber centered over the boiler room (CT-142-A-27). The fan chamber had four 14' diameter fans, directly connected to horizontal high-speed steam engines which forced the flue gases up a short stack. Fan speed was regulated automatically in response to power demand on the boilers.⁵⁴ The system was partitioned with dampers so that maintenance or repair could be accomplished on one fan while the others remained functional.

^w Economizers are pressurized heat-exchangers which hold down fuel costs by utilizing some of the waste heat normally expelled with flue gases to pre-heat boiler feed water. They also improve boiler efficiency by reducing flue-gas temperature. By reducing flue-gas temperature, its volume is reduced and this, in turn, decreases the load on the induced-draft fans (Perry, 1642.).

COOLING WATER INTAKE-1907:

Cooling water for the condensers was provided to the plant through an intake at the face of the coal dock. A series of screens filtered trash and prevented fish from entering the system. Periodically the screens were raised and cleaned with high-pressure water. A flume constructed of creosote-saturated timber conducted the water from the dock to the shore line; a concrete flume took over from there to under the turbine room. A similar flume system discharged the water into the river.⁵⁵

ASH REMOVAL-1907:

The dumping grates of the stokers conveyed ashes to a chute which discharged into hopper cars running on a narrow-gauge track in the basement. A small battery-powered locomotive was used to shuttle the ash cars.⁵⁶ The ash was run out to the tidal area east of the plant and used for landfill.⁵⁷

OTHER STEAM POWERED EQUIPMENT-1907:

A feedwater heater (heat exchanger) with 2000' of internal surface utilized the exhaust steam from auxiliaries, and was located in the boiler room basement. A Westinghouse Air Brake Company locomotive-type air compressor supplied air at 100 psi.

Compressed air was used for a variety of cleaning and maintenance purposes.

Fire protection was provided by a standard Underwriters pump with a capacity of 10,000 gallons per minute. Fire lines ran to the boiler room firing floor, the engine room and the coal dock. The pump remained in operation until the plant closed in 1986.⁵⁸

TURBO-GENERATORS-1907:

Three multiple-expansion, parallel-flow Parsons steam turbines, directly connected to Westinghouse generators, made up the original complement of equipment that powered locomotives over the 21 miles of track between Woodlawn and Stamford, Connecticut (figure 5). The turbines were operated at 1500 rpm. which was equivalent to 25 cycles, and could develop 4500 hp each. They had the latest technological advancements, including automatic safety stops, water-packed glands on the turbine shaft and adjustable water-cooled bearings equipped with a circulating oil system (CT-142-A-30).⁵⁹

The first generators in the plant were directly connected to the turbines. They were of the rotating-field type and were enclosed in a cast-iron housing which acted as a ventilating shroud. Westinghouse wound them for three-phase current but they were arranged for delivery of both single and three-phase since

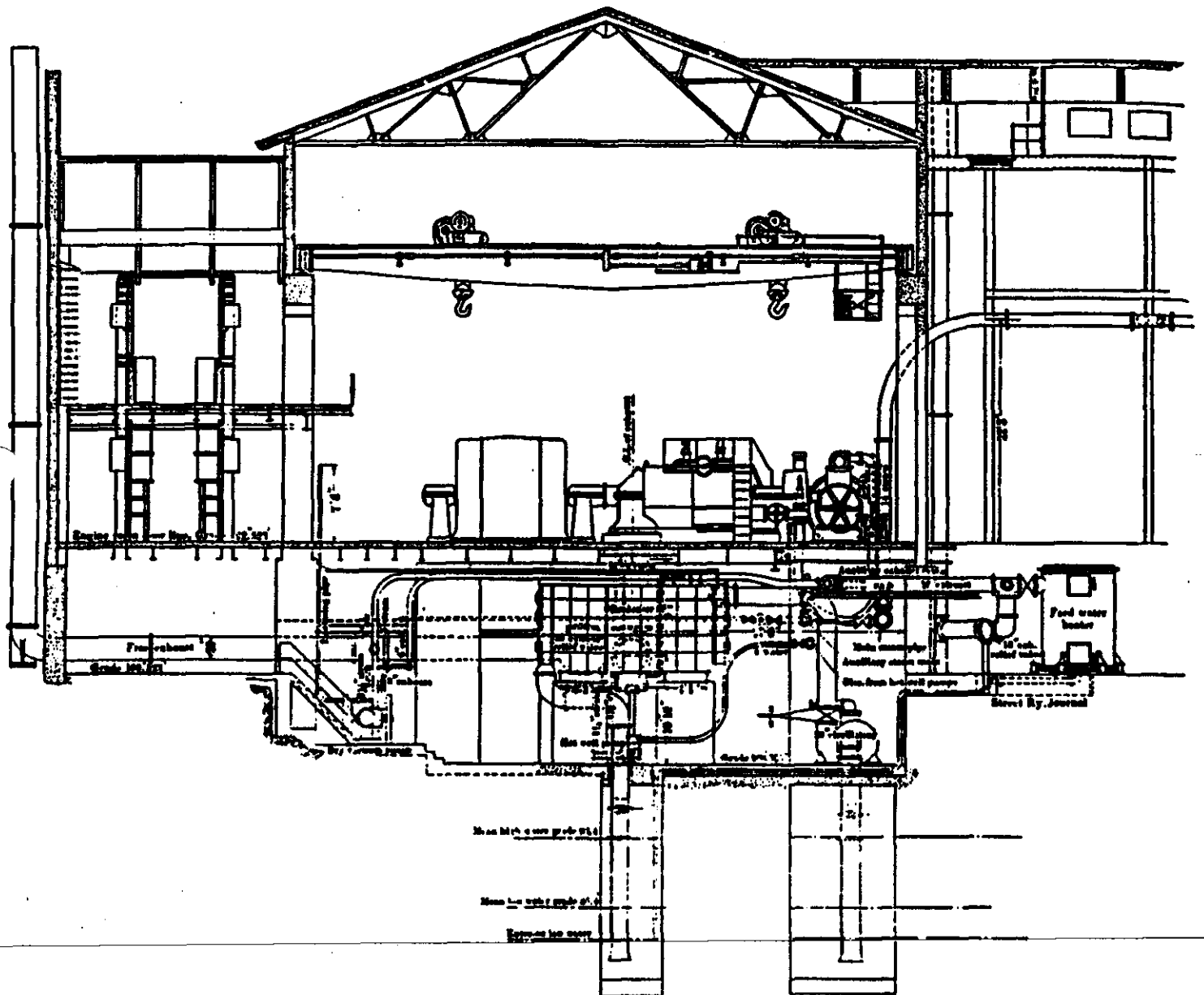


Figure 5: Section of Original Cos Cob Turbine Room, 1907
Street Railway Journal, August 31, 1907

there was significant demand for three-phase power for other railroad purposes.⁶⁰ The three generators were rated at 3000 kw., single-phase, 25 cycles at 11,000 volts. They went into service in June 1907. Exciter current for these generators was furnished by two 12 and 22 by 13 inch compound vertical engines directly driving 125 kw, 125-volt direct-current generators (CT-142-A-35).^x

Early in 1908 the three main generators were supplemented by a fourth; a 3330 kw. unit powered with an oversize Parsons turbine large enough to deliver a three-phase output of 6000 kva.⁶¹ The addition brought plant capacity to 12,330 kw (CT-142-A-41-45). However, the generators could develop at most, two-thirds of their normal continuous power rating before they overheated.⁶² They were disassembled and rebuilt four times before the trouble, identified as being caused by stray currents, was located. The engineers added a short-circuited winding in the rotating field to limit stray currents and thus reduced the overheating of the generators.⁶³

The original generators were air cooled. Air was drawn in from outside the building through a concrete and brick duct, passed through the generator and exhausted into the engine room

^x The rotating field coils of the generators had to be supplied with an external source of direct current to be magnetized. This current, called excitation, was supplied from an external generator which was driven by steam or by an electric motor.

The engines referred to were double expansion types with two cylinders, 12" and 22" in diameter. They had a stroke of 13".

basement.⁶⁴ By not exhausting air from the generators into the turbine room, the system was "practically noiseless."⁶⁵ But the setup did not provide for filtration of the air; dust accumulation could have been a problem within the generators.

CONDENSERS-Surface type-1907:

Surface condensers are heat exchangers used to reduce back pressure on the turbines by condensing steam. They increase horsepower and efficiency of the turbine. The original turbines were equipped with three-phase counter-current surface condensers manufactured by Alberger. In this type of condenser, the cooling water and the condensate do not mix and the condensate could be returned to the feedwater supply. Consequently, make-up feedwater demands were minimal. Until Cos Cob adopted Leblanc jet condensers in 1912, the railroad was able to get virtually all its water supply from Greenwich.⁶⁶

Auxiliary condenser equipment included two-stage dry air pumps, centrifugal circulating pumps directly connected to a Westinghouse engine, and a hot-well pump with a float valve control for automatically regulating its speed.

With salt-water cooling and the stray electrical currents normally found in a power house, the brass condenser tubes of the Alberger surface condensers were subject to galvanic attack. They were protected from this type of corrosion by applying a DC

counter electromotive force which was generated by a small motor generator set.⁶⁷ This neutralized stray currents and eliminated corrosion.

ELECTRICAL DISTRIBUTION-1907:

The cables from each generator ran directly to the switchboard gallery and from there to oil circuit breakers.^y From the breakers, insulated cables connected to two high-voltage buses under the gallery. Knife switches were used to disconnect the breaker from the bus. Each leg of the bus was made of two 3" x 1/4" copper bars enclosed in a brick-walled compartment with a soapstone cover. The buses were supported on porcelain insulators within the compartment. The buses were interchangeable and could be used separately. The design made it possible for each generator to be operated independently for maintenance and testing. System feeder cables passed through choke coils before

^y High tension oil switches: High-voltage electricity will form an arc and jump across an air gap. The distance it will jump is a function of voltage. When switches which control high voltages are opened, a destructive arc will be formed, ionize the surrounding air and continue to conduct current across the switch gap. To prevent this from occurring, the Cos Cob facility used circuit breakers in which the switch contacts were opened while immersed in an oil bath. The oil has a much higher dielectric constant than air. This prevented the formation of a destructive arc when a high-voltage circuit was opened (Cravath and Trow, 1907).

exiting the building through special glass windows.^{68z}

With single-phase transmission, one leg of the bus was grounded directly to the track rails on the right-of-way. Another leg supplies the feeders which were directly connected to the trolley wire. The locomotive motor completed the circuit between the trolley and the rail. The third leg of the bus was carried along the right-of-way to provide power for other railroad uses such as repair facilities or station lighting.⁶⁹

Anchor bridges at two-mile intervals provided tension support for the overhead wires and carried an 11,000 volt lightning arrester. At each end of the anchor cross-truss, an 11,000-volt shunt transformer was located, one was connected to a bus-bar which ran around the circuit breakers. The other transformer was connected directly to one of the "power" feeders. The power feeder formed one leg of the third phase of the generating system. Thus, in the event of damage to the trolley-wire section, power for operating switches and signals was still available.⁷⁰

SWITCHBOARD-1907:

The switchboard was made of marble slabs. It had four panels

* Choke coils are also known as reactors. They are devices which limit the current surges if a short circuit or fault occurs on the line. The main generator reactors at Cos Cob were air and porcelain insulated coils of stranded, sulphated copper wire.

for the operation of the generators, three panels for the exciter generators, two for Tirrill voltage regulators, a load panel, a Synchroscope panel and five panels devoted to control of the outgoing feeder system and local circuits (CT-142-A-36, 37, 40).

The Tirrill voltage-control device was the key to maintaining constant voltage on the system. The Tirrill regulators controlled voltage on the exciter generators. Tirrill-type controls were still in use when the plant shut down in 1986. An interesting feature of the earliest Tirrills was the method of adjusting the calibrating weight. Pieces of lead shot were added to a small bucket until mechanical balance was achieved. Electrical voltage regulation depended on a mechanical balance beam.²² A shot-balanced Tirrill was still in use when the plant

²² The first successful regulator (automatic rheostatic type) was invented by Allan A. Tirrill of Westinghouse.

The earliest type of vibrating regulator for control of voltage of a direct-current generator was developed by Edison. It consisted of an electromagnet connected across the output of the generator to be regulated. The armature of the electromagnet opened a pair of contacts against the tension of a spring. These contacts operated a relay carrying larger contacts, which short circuited a generator field rheostat. The contacts remained closed until the generator voltage built up sufficiently to overcome the tension of the control spring and opened the control or main contacts. At this instant the relay contacts opened, thereby introducing a block of resistance into the shunt field circuit. This caused a reduction in generator voltage. A slight decrease in voltage caused the main contacts to close, thereby closing the relay contacts and short-circuiting the field rheostat, making the generator voltage build up. In this way, the relay contacts across the generator field rheostat were rapidly opened and closed, so that the average or effective resistance across the field was just sufficient to maintain a constant line voltage.

closed.

INTRA-PLANT COMMUNICATIONS - 1907:

Several systems for communications among operating personnel at the plant were used. Telephones connected the switchboard gallery with the turbine hall. Each turbine communicated with the basement-level pump room by speaking tube. A gong was used to call attention to an annunciator board where lighted transparent signs directed specific action to be taken by the watch engineer. The fan room and the pump room were connected with the boiler room by speaking tube. Coal conveyor communications were carried out with bell signals. Specific individuals were called by personalized air whistle signals.⁷¹

THE CATENARY SYSTEM-1907:

The New Haven's 11,000-volt overhead catenary system took

The line voltage would continually build up and down throughout the range of a fraction of a volt, but so rapidly that the average voltage was substantially uniform.

The vibrating regulator just described was similar in construction to a type of telegraph instrument. The same idea of automatically regulating the voltage of a direct-current generator by rapidly opening and closing a pair of contacts across its field was employed in a later type of regulator developed by Tirrill. Instead of using telegraphic equipment, Tirrill used a solenoid provided with a stop core which was extremely sensitive to voltage changes.

over from the New York Central's third-rail system which originated at Grand Central Station, and ran as far north as Woodlawn, New York. (Both systems are currently owned by Metro-North.) The double catenary was installed from Woodlawn to Stamford in 1906. The catenary is supported on riveted steel bents or bridges embedded in concrete bases spaced 300' apart along the right of way.^{bb} Its most distinct characteristic was a series of triangular hangers strung along two messenger strands made of seven strands of high-strength steel. The hangers diminished and increased in size in proportion to their distance from the steel bents. Hangers were adjusted in length so that the trolley wire was maintained in a horizontal position, 6" below the catenary cables at the middle point of the span. This design gave lateral stability to the contact or trolley wire.

The original copper trolley wire was subject to severe wear. An analysis of wear patterns resulted in the addition of a 4/0 grooved contact wire below the original copper contact wire. Steel and surface-hardened copper were eliminated in favor of a bronze alloy for this contact wire.

On curves, the contact wire was held approximately over the

^{bb} Alfred Carleton Gilbert was traveling to New York on the New Haven Railroad while the catenary was being built. He was fascinated by the steel bents and bridges being erected to carry power lines. In a flash of inspiration he conceived the idea of assembling similar beams on a smaller scale. By 1913, A.C. Gilbert was displaying his first Erector sets at the New York Toy Fair. They were an immediate hit and Gilbert was on his way to toymaking fame (Townshend 1970:110).

center of the track by intermediate "pull-off" wires which created a series of chords roughly following the center line of the track. Maximum displacement of the trolley from the locomotive pantagraph's center was 10".⁷²

THE 1911 EXPANSION AND BEYOND:

By 1911 Cos Cob had undergone a thorough trial period. Electrified commuter service was operational, but two technical problems remained unsolved. First, the electrical power transmission system created unacceptable interference and noise in neighboring telephone and telegraph circuits. Second, even with the alternating-current system, the voltage available at the outer limits of the system was insufficient for normal operation.

In addition to solving these problems, the engineers were obliged to comply with management plans for extension of electrification east to New Haven as well as to the Harlem River branch and freight yards. At the time, the Harlem River branch was a six-track branch, 11.23 miles long, extending from New Rochelle to the Harlem river. It was the main freight artery for traffic between New England, New York City, and the west.⁷³

⁷³ At the Bay Ridge and Oak Point terminals of the Harlem River Branch, freight cars were loaded onto barges which would be towed across New York Harbor and off-loaded at Greenville, New Jersey, into the trunk-line systems to the west and south. Until the New Haven gained access to New York via Hell Gate Bridge and the Pennsylvania Railroad tunnels, through passenger trains to

The building was doubled in size and additional boilers and turbo-generators were installed to carry the load. The critical problem was to design an improved circuit capable of supplying full power to the extremities of the system. The modifications of 1911-1913 addressed and ultimately resolved those problems.

ELECTRICAL DISTRIBUTION CHANGES-1912:

The voltage-drop problem experienced with the original electrical plan could have been solved by raising the transmission voltage; that in turn would have required changing 350 miles of insulated wire as well as transformers and other components on the locomotives. Analysis showed that in the 1907 circuit all the current flowed in the trolley wire and the rails in the same direction; outward, toward the ends of the system. The new transmission circuit set standards which lasted for the life of the Cos Cob power plant.

Under this transmission scheme, generators did not feed the trolley wire and track directly. Instead, the generators were

Philadelphia and Washington were also "floated" and bypassed New York City.

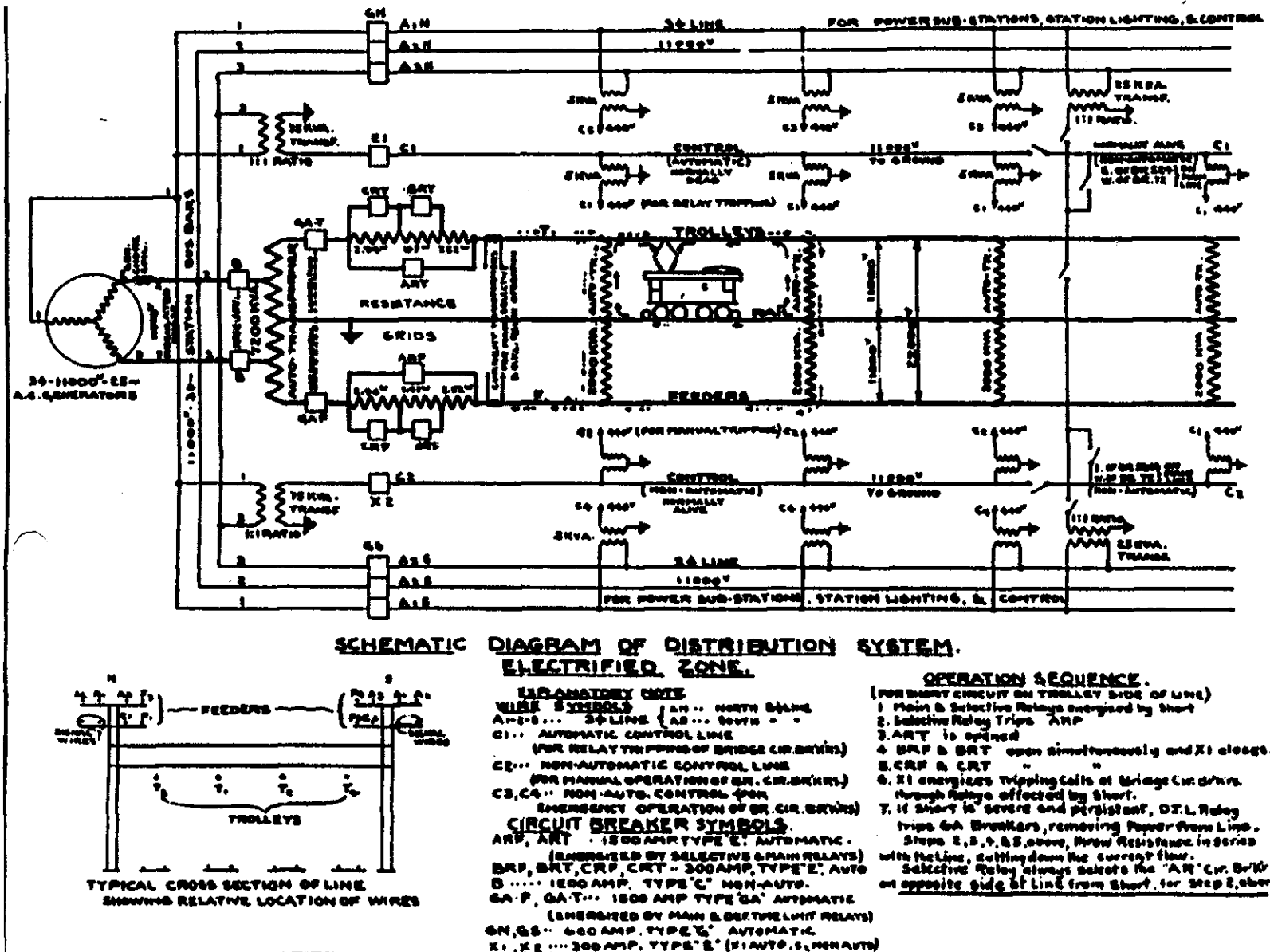
Oak Point was the end of the Harlem River Branch and the freight interchange with Central RR of NJ and Lehigh Valley. Oak Point had eight float bridges (docks) for handling freight. They would interchange 1000-1100 cars per day over a float distance of 3 1/2 miles. The other New Haven facility was at Bay Ridge. Bay Ridge had four float bridges with six tracks and a capacity of twenty-three cars each (CONNHM&A-IFIP, 5-6).

connected to 22,000-volt autotransformers. The autotransformer center tap was grounded to the rails. One terminal of the transformer was carried to the trolley wire and the other to a feeder wire. The traction circuits were rearranged to form a "three wire" system. The rails formed a neutral between the overhead trolley and a feeder wire. Potential between trolley and feeder was 22,000 volts. Between rail and trolley or feeder and rail it was 11,000 volts. The circuits and distribution system are shown in figures 6 and 7.

Additional autotransformers were located at intervals along the main line which broke the line into isolated sections. These transformers were connected between the trolley and the feeder with their center taps grounded to the rail. Their function was to reduce the feeder voltage from 22,000 to 11,000 for locomotive use. In essence, what the new configuration did was break the line into shorter sections, with each section fed with electricity coming directly from the powerhouse. There were twenty-four sections on the system. With alternating-current, the higher the voltage, the less the line loss. Conversion to the working voltage of 11,000 volts took place near the point of use and line losses were cut dramatically. The new configuration also

Figure 6: Westinghouse Electric & Manufacturing Company, 1924





Schematic Diagram of Distribution System, Showing Current Limiting Equipment and Auto-Transformers
Figure 7: Westinghouse Electric & Manufacturing Company, 1924

cut down communications interference. Further reduction in static was achieved by encasing telephone and telegraph wires in a 45-pair lead shielded cable.⁷³ To carry the additional feeder and signal wires, each side leg of the catenary bridges was extended upward.⁷⁴

Even with the additional generators, growth in traffic forced the New Haven to buy peak power. Additionally, the New Haven contracted to supply power to the New York, Westchester and Boston Railway. The New Haven started purchasing a minimum of 40,000,000 kilowatt-hours per year from United Electric Light and Power Company (New York Edison) starting September 1, 1915. This power was generated at the Sherman Creek Station located at 201st Street and the Harlem River in New York City. It was transmitted through an underwater conduit to a substation at West Farms, the junction of the New York, Westchester, & Boston Railroad and the New Haven's Harlem Branch.⁷⁵

COAL, 1910-1919:

A trestle for unloading coal delivered by rail was built in 1910 (CT-142-A-22). The trestle ran through a gable-roofed frame building with clapboard walls which housed coal-crushing and conveying machinery. Hopper cars were winched over the trestle tracks and opened to discharge coal into a crusher housed beneath the structure. This crusher was later made part of a consolidated

system which also crushed coal delivered by barge. The crushed coal moved down a trough and was picked up by a bucket conveyor. Coal was then transferred to a horizontal belt conveyor that fed the concrete bin located under the floor on the north end of the boiler room.⁷⁶

When the west boiler room was added in 1912, fuel consumption approached 350 tons per day. With temporary storage for 350 tons outside and a 350-ton underfloor bunker at each boiler room, maximum reserve capacity was three days' coal supply.

During World War I barge coal delivery was unpredictable; a three-day stockpile was inadequate. The need to make Cos Cob secure from fuel shortage had a higher priority than tasteful design; practical coal-handling systems gradually wiped out the Spanish-mission architecture. An outdoor storage facility for 10,000 tons of coal was built in 1919. The original crane on the dock continued to unload barges with its clam shell bucket and load it into the cable cars where it was transported to the smaller internal bunkers on the south end of the boiler rooms.⁷⁷

As part of the 1919 coal-handling renovation, two elevated 1000-ton concrete bunkers on the north side of the boiler rooms were added (CT-142-A-12). The transfer system was re-engineered to deliver coal received by either barge or rail into the new 1000-ton bunkers on the north side of the plant.

The core of the system was a Robins radial bridge conveyor. (CT-142-A-19-21) Its axis was centered on a 10,000-ton coal storage pile and it could be swiveled into position to deposit or retrieve coal from any part of the pile by means of a clamshell bucket. Coal delivered by barge was unloaded by means of the clamshell bucket into a chute under the center axis of the bridge. From this chute, coal fell on to a swinging-boom conveyor which would deposit it in a storage pile located anywhere within the perimeter of the circumferential single track supporting the outer end of the radial bridge.

To get the coal from this storage pile into the plant, the swinging-boom conveyor would be positioned over a chute located on the north side of the pile. This chute led to the crusher under the railroad trestle. The clamshell bucket on the radial bridge picked up coal from the pile and deposited it into its central hopper. From the central hopper, coal dropped onto the swinging boom conveyor which fed it into the chute leading to the crusher under the trestle.

The early plant, with its inside storage bunkers, avoided a problem that arose later, the prevalence of wet and frozen coal. Wet coal removed from the storage pile during snowy or rainy weather adhered to chutes and did not flow smoothly to the pulverizer or stoker. The coal would freeze into a monolithic mass which required dynamite to break it up. Sometimes most of the work force, including supervisors, would be assigned to break

up frozen coal and keeping it flowing.^{78dd} Three brick furnaces were built under the trestle to thaw frozen coal in winter. A hopper car would be positioned over the furnaces and heated for two to twelve hours. If it wasn't too cold, the coal thawed and the car could be emptied.

The new 1000-ton bunkers were filled by means of an inclined conveyor reaching from the crusher under the coal trestle to the top of the east bunker and then across to the west bunker. A walkway connected the tops of the bunkers.⁷⁹ Coal delivered by rail continued to be dumped from the hopper cars into the crusher under the trestle and used the same inclined conveyor to reach the bunkers.

The original flight conveyors inside the boiler room were replaced by larry cars.⁸⁰ Coal was deposited from the bunkers into weighing larries holding 2-1/2 tons each. These larries rode on overhead tracks over the firing aisle.^{ee}

The tracks for the weighing larries were extended outside the building and under the 1000-ton elevated bunkers so they could be filled by gravity. During a stoker filling operation with coal from the 1000-ton bunkers, the larries traveled from

^{dd} Fred Mutino, last Chief Engineer of Cos Cob kept a coal poker, a steel rod about four feet long, in his office as a reminder of his first job as a laborer moving coal (Stangl 1986:6).

^{ee} A larry or lorry is a cart used to transfer material from storage to point of use. Generally, the larry has a weighing function and can deliver pre-weighed charges to its destination.

north to south along the firing aisle on the overhead tracks and deposited coal in the hoppers of each boiler. The larry cars could also transfer coal from the old bunkers at the south end of the boiler room. On a transfer run with barge-delivered coal brought in by the old cable car system, they traveled along the suspended tracks over the firing aisle from south to north and deposited coal in the stoker hoppers of each boiler. It required five men to run the coal transport and storage system.

BOILERS-INDUCED AND FORCED DRAFT:

To supply steam for the electrification expansion program of 1911-1912, the west boiler room was added (figure 8). It contained fourteen 620-hp Bigelow-Hornsby boilers, each having 6250 square feet of heating surface. The boilers were designed for counter-current circulation with the hottest water proximate to the hottest gases and the coldest water meeting the coldest gases. These boilers also operated at a pressure of 200 psi, 125 degrees superheat and were fed with bituminous coal through seven retort underfeed stokers. The stokers were driven through a power take-off, gears and flexible couplings from the induced-draft fan turbine. Induced-draft fans equipped with water-cooled bearings were located between the economizers and the 12-1/2' diameter metal stack.⁸¹

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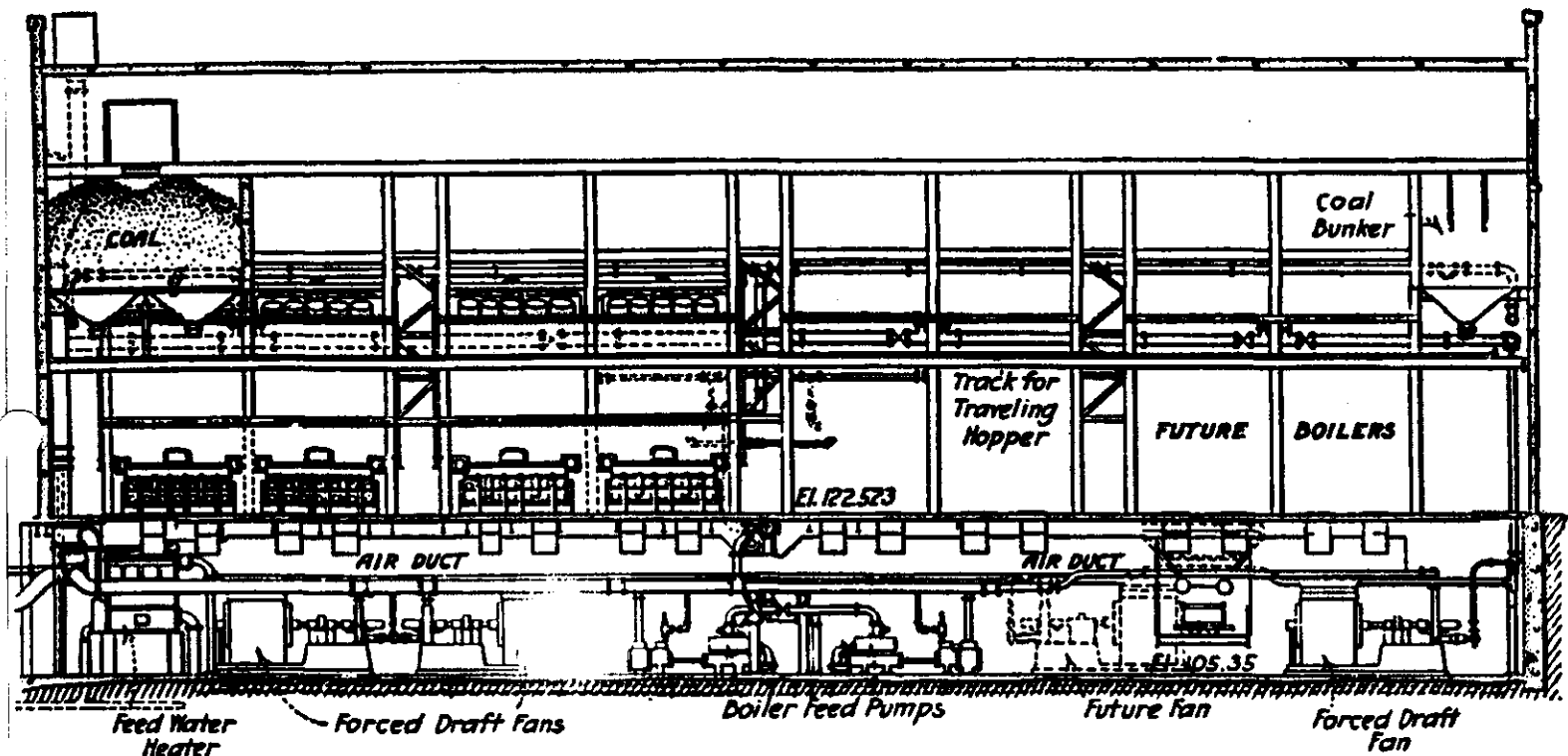


Figure 8: Side Elevation of Boiler Room, 1912
 Power - March 16, 1915

There were also three double-inlet, forced-draft turbine-driven fans located in the pump room. They delivered 95,000 cubic feet per minute per fan. The feeding of the stokers and the speed of the fans were automatically regulated by the boiler pressure acting on a valve which controlled the steam supply to the fan and stoker drive turbines.⁸² The combination of forced and induced draft is called balanced draft. It was only the second installation of its kind in the United States.

ECONOMIZERS-1912:

Three economizers served the fourteen new boilers. Dampers regulated the flow of flue gases through the economizers and could be arranged to bypass them completely.⁸³

JET CONDENSERS-1912:

In 1912 the four new Westinghouse 4000-kilowatt turbo-generators were equipped with Leblanc jet condensers rather than the surface condensers used on the 1907 turbines (CT-142-A-31). The jet condensers functioned by spraying a coarse mist of brackish cooling water directly into the steam exhausted by the turbine. The mixture of cooling water and condensate was removed from a common sump or hot well by a pump. A steam-operated air ejector removed gas from the system. Since Cos Cob used brackish

water for cooling, the mixture of condensate and cooling water could not be recycled to the feedwater system; as a consequence, boiler feedwater volume requirements increased substantially. A total of 750,000 gallons of cooling water per hour flowed through the system.⁸⁴

A STEAM LAUNDRY:

A small steam laundry was located in the west basement adjacent to the condensers. The equipment was similar to steam-powered laundry equipment used on ships. No dates were found on the equipment and it predates the recollection of the oldest employee interviewed, which would indicate a date prior to World War II. It was an amenity that had not been officially supplied by the railroad. The laundry equipment consisted of a small cast-iron chamber having a capacity of about two cubic feet. The operator loaded it with dirty clothes, water and soap then admitted live steam. The steam tumbled and "scrubbed" the clothing. A steam-driven centrifuge and several metal frames used for stretching pants completed the outfit. Employees would get their work clothes cleaned at the plant rather than at home. The operation of the laundry was an unofficial assignment of one worker who traditionally was compensated with an occasional carton of cigarettes for his extra service.⁸⁵

DRAINAGE FLUME AND THERMAL EFFECTS:

The new jet condensers returned a mixture of condensate and cooling water to the Mianus River through a flume emptying into a small cove to the south of the coal dock. Sufficient heat was added to the environment to warm the cove and create a habitat for species normally found in more southerly waters. Local fishermen found Jack Cravelle, Needle Gar, Diamond Back terrapin, a unique species of striped bass and white perch in the waters adjacent to the plant cooling water exit.⁸⁶

TURBO-GENERATORS 1912:

In 1912 four additional units of 4000 kw. each were added. This brought total plant capacity to 28,300 kw.⁸⁷ These were located in the expanded turbine room.⁸⁸ (figure 9). At the completion of the project the plant's equipment comprised a total of eight steam-driven turbine generators, varying in size from 3000 to 4000 kilowatts. There were twenty-eight boilers on line which used 3 lb. of coal per kilowatt hour or 350 tons of coal per day. The plant was generating 90 million kilowatt hours per year.⁸⁹

Fan sections on the generator rotors themselves pulled in the air for cooling the generators. To remove dust from the air used for cooling the generators it was passed through a spray of

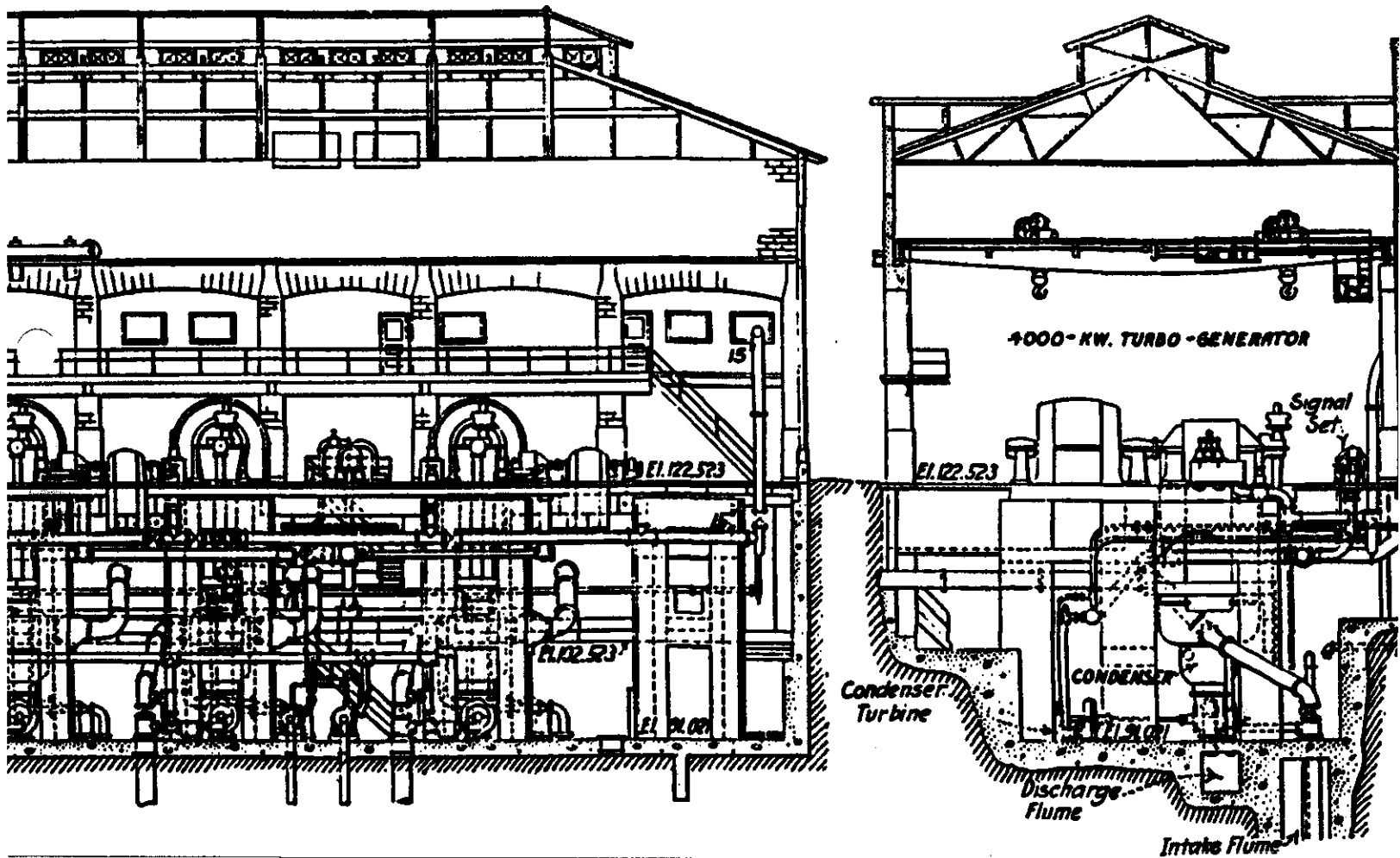


Figure 9: Side and End Elevation of Turbine Room, 1912
 Power - March 16, 1915

water and conducted through a labyrinth made of corrugated galvanized iron sheet. The water spray entrapped airborne dust. Dust contaminated water dropped out of the cooling air stream as it went through the tortuous passages of the labyrinth. The generators exhausted into the turbine hall.

GENERATOR FIRE CONTROL:

The generators were protected from fire by a steam smothering system. In the event of fire, a damper closed off the air intake and steam was injected into the duct under the generator. The steam would snuff out any fire instantly.

EXCITER GENERATORS-1912:

The new generators were excited by two turbine-driven 125 kw, 125-volt direct-current generators driven through a reducing gear from one turbine. Two additional exciter generators were driven by 190-hp. induction motors.⁹⁰

SIGNAL POWER-1911:

Two turbo-generators having a capacity of 130 kw. each, delivered 2300-volt, single-phase, 60-cycle alternating-current at 3600 rpm. There was also a motor generator set which had a 500

hp., 440-volt induction motor and a 450-kva, 2300-volt alternating-current, three-phase, 60-cycle generator. It ran at 720 rpm and was used for operating railroad signals.⁹¹

THE COS COB PLANT AFTER 1923:

Commuter traffic on the New Haven continued to grow in the 1920s. In 1921 one out of ten or eleven persons riding on a United States railroad rode on the New Haven. There were 130 road miles (570 track miles) of electrified line on the New Haven. The railroad owned 108 electric locomotives, seventy motor cars and ninety-five trailers which produced 335,000 passenger miles per month, 160,000 motor car miles, 75,000 freight locomotive miles and 70,000 yard locomotive miles. There were forty-one of the original type of passenger electric locomotives still in service. They had been in use for fifteen years and were averaging 150 miles per day.⁹² The peak of electrification was reached in 1927 with 700 track miles of the New Haven under the catenary.⁹³

GENERATORS:

In 1923 one of the original 3000 kw. turbo-generators was replaced by a 9,000-kw. unit.⁹⁴ This brought plant capacity to 34,300 kw. The lineup in 1924 was:⁹⁵

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No.	kw	Dates
1	9,000	1923-1986
2	3,000	1907-1925
3	3,000	1907-1926
4	3,300	1908-1940/41
5	4,000	1911-1945/47
6	4,000	1911-1945/47
7	4,000	1911-1945/47
8	4,000	1911-1945/47

Turbo-generator units 2 and 3 were replaced in December 1925 and December 1926 respectively with 9,000 kw units. Number 4, installed in 1908, was removed and scrapped in 1941-1942. From 1945 to 1947, the remaining original turbo-generator unit numbers 5, 6, 7 and 8, were scrapped.* The new lineup, which lasted until the plant closed was:

No.	kw	Dates
1	9,000	1923-1986
2	9,000	1925-1986
3	9,000	1926-1986

Replacement of the original turbo-generators numbered 1, 2, and 3 was not a simple matter. The conversion from surface to jet condensers required removal of bedrock and increasing basement and foundation depth inside an operating plant. In addition, electrical service to the railroad had to be maintained. Much of the rock removal had to be done by hand to avoid damaging operating equipment.

SHORT CIRCUIT AND FAULT CLEARING-1924:

The electrical feed from the plant was taken through

Westinghouse C.O. 22-type breakers installed in both trolley and feeder phases. These formed the main protection for the power plant in the event of line trouble. The feed passed through duplicate sets of circuit-breakers which normally short-circuited resistance grids. In the event of trouble on the line, these circuit-breakers opened consecutively, and put the grid resistors into the circuit in three steps. After the resistance was all in series with the load, a control circuit extending along the right-of-way activated and this energized the trip coils of the local bridge-type circuit-breakers that were short circuited. The grid resistors reduced current to 2300 amps, which could be handled by the breakers on the anchor bridges. The short would then be automatically cleared by cutting out the shorted sections. As soon as the line was cleared, the resistance circuit-breakers went back to their normal, short-circuited condition, taking the grid resistors out of the circuit. There is complete redundancy in the system.⁹⁷

WATER:

A second 600,000-gallon water tank was built in 1923 just south of the existing water tank.⁹⁸ Water supplies were adequate until 1927. When the Greenwich Water Company and the crib dam and pumping station at Mianus could no longer meet demand, a new, higher stone dam and pumping station was built close by. Three

diesel-powered pumps supplied water to four sand-gravel filters which fed the plant through a 16" pipe (figure 10). In 1953 an electrically driven pump replaced one of the diesel pumps and the Mianus pumping station went on automatic operation.⁹⁹

BOILERS-1927:

Boiler design had come a long way since the plant was originally built. New boilers were larger, and they put out much more steam per unit of physical volume. They were more efficient than smaller units. The New Haven began replacing the boilers at Cos Cob with units that ran on pulverized or powered coal in 1927.¹⁰⁰ The first units were designated numbers 900 and 901.

The Ladd-Combustion Engineering boilers were designed for eventual operation at 325 lbs. and 600 degrees F.¹⁰¹ The new coal pulverizing technology exposed a large surface area of fuel to combustion air and accelerated burning. Cos Cob used a unit system of pulverization in which the coal was ground just before it was burned. A stream of primary air carried the powdered coal from the pulverizer through the burners and into the combustion chamber. Secondary air was injected around the burner. Combustion occurred with the powdered coal suspended in free space within the chamber; there were no conventional grates.¹⁰² Pulverized-coal firing, while very efficient, required the installation of

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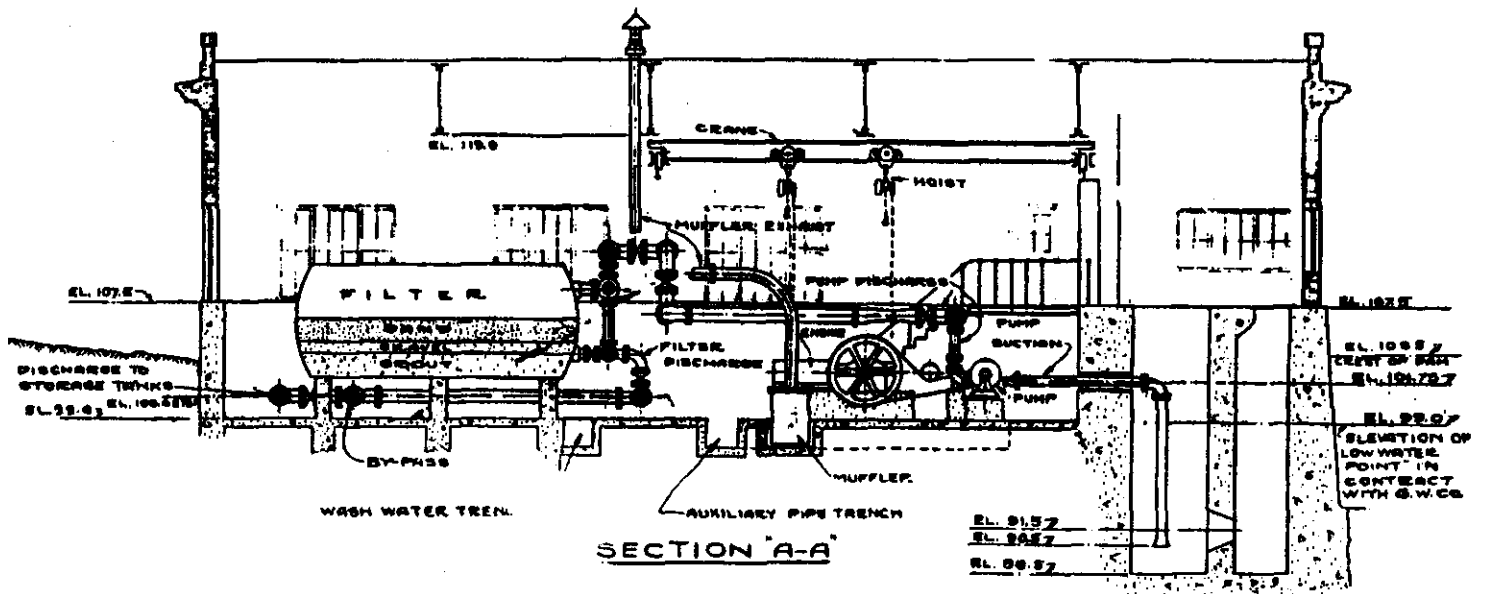


Figure 10: Section of Mianus Pumping Station, 1927
New Haven Railroad-Mianus River Plant-BP 6225-UCONNHA&M

high-efficiency fly-ash collection systems to trap fine particles and visible emissions.

In 1927-1928 the new boilers were installed in the empty space in the east boiler room originally reserved for two 12,000-lb. per hour boilers. Each was rated at 70,000 lbs. of steam per hour and could be fired up to three or four times this rate for brief periods.

The station was required to supply a base load of 9,000 kw. during this period; the new boilers could easily handle it. The older units were fired to provide peak power loads up to about 30,000 kw. With the use of pulverized coal, consumption was cut to 2.2 lbs. per kwh.¹⁰³ The use of pulverized coal had resulted in substantial fuel economies.

The first two pulverized-coal boilers had "Sirocco" bag-house dust collectors and Western Precipitator Company "Dust Eliminators."¹⁰⁴ In 1933-1934 two additional pulverized-coal boilers generating a total of 220,000 lbs. of steam per hour replaced the fourteen Bigelow-Hornsby units whose total capacity was 150,000 lbs. per hour. The new units were also made by Bigelow with burners manufactured by Combustion Engineering Corporation.¹⁰⁵ They were designated numbers 902 and 903 (figure 11). As a result, coal consumption dropped from 2.2 to 1.7 lbs. per kwh. In 1936 the fourteen Bigelow-Hornsby boilers were removed from the west boiler room and scrapped. By 1938 the plant was able to increase operating steam pressure from 200 to

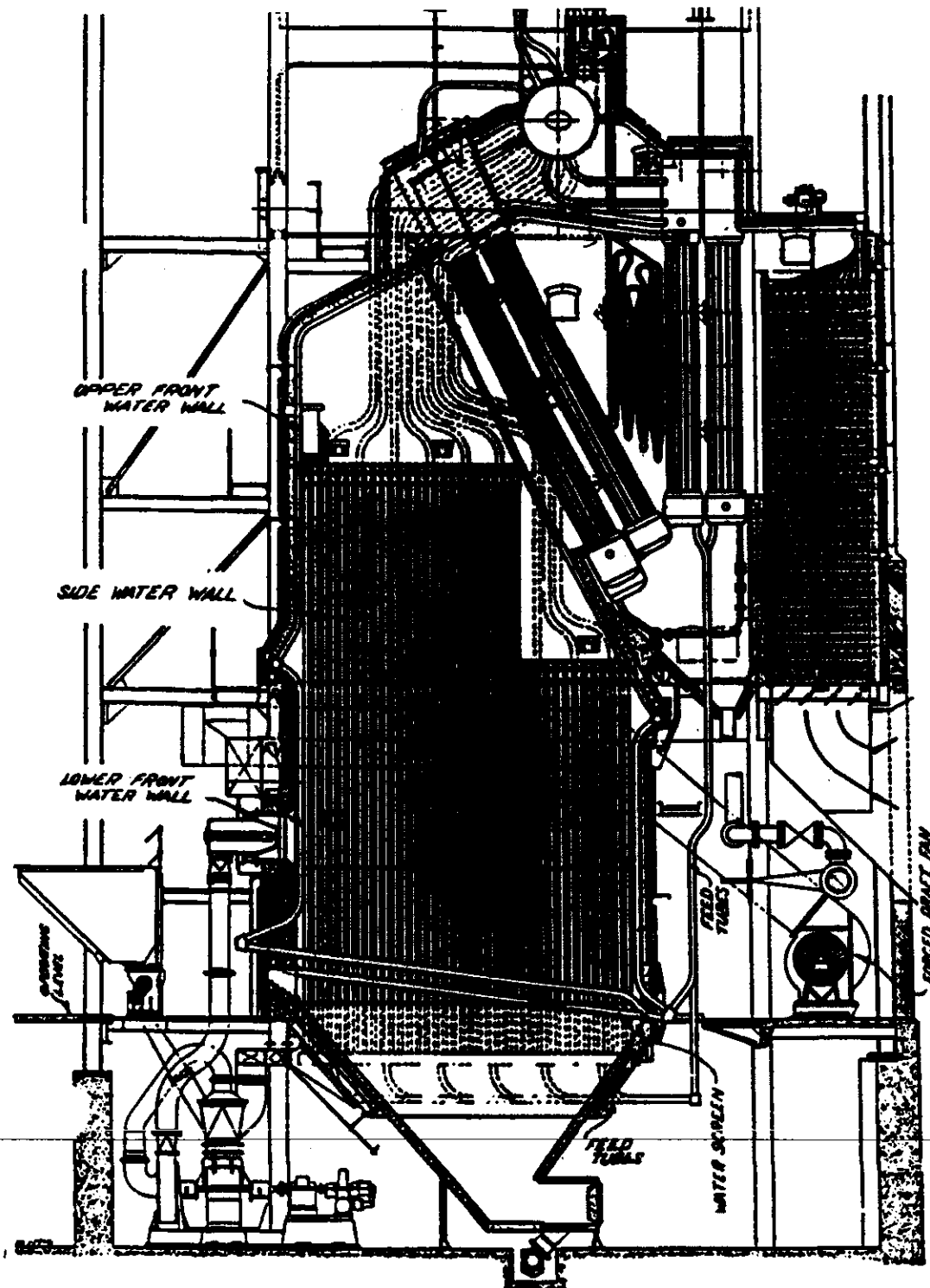


Figure 11: Section through Boiler 903/904, 1933
Power Plant Engineering-May 1935

325 psi. Coal consumption dropped from 2.2 to 1.7 lbs. per
kwh.¹⁰⁶

Experience indicated the need to remove oxygen from
feedwater to protect the boiler tubes. A deaeration unit was
added which was effective but did not meet its capacity
guarantees. Consequently, price concessions were obtained from
the manufacturer.¹⁰⁷

COTTRELL PRECIPITATORS:

To capture the fine fly-ash resulting from pulverized-coal
firing, bag-house filter type dust collectors were not entirely
satisfactory; The 1933-1934 boiler installation was equipped with
Cottrell electrostatic precipitators.^{ff} The Research

^{ff} In 1905 Dr. F.G. Cottrell, professor of physical chemistry
at the University of California, developed the first commercial
electric precipitator. It consisted of a precipitation chamber in
which the suspended particles were removed from the gas. It also
required a high-voltage transformer and rectifier to create a
strong electrical field in the chamber. Precipitators typically use
voltages of 15,000 to 100,000 volts to charge dust particles and
drop them to the bottom the chamber.

Cos Cob's Cottrells used full-wave mechanical rectifiers
driven by synchronous motors--in effect a pulsed DC. Six gap half-
wave rectifiers were used to power two Cottrells, first pulsing one
then the other.

The single-stage Cottrell is generally used for dust
collection from flue or process gases. A corona discharge is
maintained throughout the precipitator chamber and prevents re-
dispersion of precipitated smoke particles.

The Cos Cob unit used twelve gauge rods as vertical

Corporation's bulletin of 1929 noted the need for this technology:

Under certain conditions--notably where the plant is near a residential neighborhood--it is desirable, as far as possible, to eliminate this ash before it is discharged into the atmosphere.¹⁰⁸

The Cottrell precipitator worked by passing flue gas between vertical concrete plates and rod-like metal electrodes. The electrodes were charged with 88,000 volts from a six-gap rotary rectifier. The charged concrete plates attracted and collected smoke particles. Particles were removed by scraping down the concrete with chains. Later-model Cottrell precipitators used vibration to remove the particles of fly-ash. The ash was discharged from the Cottrell hoppers into a vacuum system which carried ash to a hopper at the top of the plant. The ash was mixed with water and sluiced away to a landfill area through a pipe. The ash-disposal system was extended to include boilers 900 and 901.¹⁰⁹

electrodes. Collection plates were concrete two inches thick, spaced ten inches apart. The rods were centered between the plates approximately six and three-eighths inches apart. The Cottrells were supposed to remove 90 percent of the fly ash when operating properly. Experience showed removal was 40 to 60 percent of particles larger than 50 micrometers (Anonymous 1929:2-3).

TRANSFORMER OIL:

The Cos Cob plant had the means for testing the electrical breakdown point of the oil used in switches, transformers and circuit-breakers. It was a powerful transformer that supplied a variable voltage to two electrodes in a small Bakelite cup which held the oil sample. The voltage on the electrodes would be gradually raised until an arc formed through the sample. The voltage to accomplish this would be recorded on a meter. Oil that did not meet the standard would be sent to an on-site purification plant where it would be run through a filter press and cleansed. Most of the oil in the plant was recycled, very little make-up oil had to be purchased.¹¹⁰

COAL 1935 & 1948:

In 1935 a new belt conveyor to the bunker in the south end of the boiler room was installed. It replaced the cable railway system that had been in place since the plant began operation.¹¹¹ Modernized components included a chute which was filled by the clamshell bucket on the radial bridge, and an inclined conveyor which carried coal from the chute to the top of a crusher. After dropping through the crusher, coal was carried by a short horizontal conveyor to a vertical bucket conveyor. The bucket conveyor lifted the coal to the top of a tower. From this point

the coal was deposited on a conveyor belt which ran to the top of the west boiler room and discharged into the original internal bunkers.

More powerful small bulldozers appeared on the scene after World War II. A bulldozer-based coal handling system designed by Gibbs and Hill in 1947 was installed. The Robins radial bridge coal conveyor was scrapped and removed in 1948 because it was expensive to maintain and created dust problems. It also posed a significant fire hazard. Two bulldozers were provided to pile the coal and move it to the conveyor hoppers.

The bulk of coal was being delivered by rail. Hopper cars were winched out on to the trestle and emptied. The coal was either immediately crushed and conveyed to the east 1000-ton bunker or deposited via a boom-type conveyor into a storage pile (CT-142-A-24) which would be piled and moved with a bulldozer.

Two hoppers were constructed in pits at ground level. The southernmost underground hopper supplanted the chute which had been fed by the radial bridge clamshell bucket. Coal was bulldozed into this ground-level hopper and then discharged onto the existing conveyor which had been fed by the chute. The coal then followed the existing route through the crusher via the bucket and belt conveyors into the south internal bunkers.

Stored coal could also be directed to the external 1000-ton bunker on the north side of the west boiler room. The bulldozer pushed coal into a pit hopper adjacent to the coal-crusher house

located over the trestle. This pit hopper discharged stored coal onto an inclined conveyor which fed the trestle coal crusher. From there crushed coal was moved to the eastern 1000-ton bunker on the inclined conveyor belt that had been built in 1919. This system was used until 1980 when the plant switched from coal to oil and gas under a court order issued in 1978.¹¹² No coal was burned after the autumn of 1980.

CONTROL EQUIPMENT:

"Black boxes" crammed with transistors, integrated circuits and computer logic didn't exist when Cos Cob was designed. The plant used electromechanical control equipment. Leslie N. Crichton, of Westinghouse, described one aspect of the Cos Cob control system in a 1937 paper.¹¹³ Cos Cob was using motor generators to provide DC for exciting the main generators. Under load conditions it was possible for the generator poles and the motor poles to "slip", electrically speaking. Electrical slippage might continue until the poles came back into step one full revolution later. The danger was that a series of surges caused by an out-of-step condition would put a torsional or twisting strain on the shaft that connected the motor and the generator, resulting in eventual destruction of the machine.

In his paper, Crichton described an ingenious detector for this condition. A series of latching or notching relays reacted

to current surges caused by the out-of-step condition. One or two surges over a ten second period were not cause for concern. But if seven relays latched in ten seconds, a problem existed and operator action was required. After a non-critical ten-second period, the timer would reset all the relays to the open condition. The notching relay is a good example of the type of electromechanical device used to control Cos Cob power.²²

When two or more alternating-current generators were placed on line, they had to be synchronized. That is, the positive and negative swings of the alternating-current cycle of each generator had to be matched together. At Cos Cob this was done manually, using a Synchroscope to guide the operator and let him

²² Crichton's paraphrased paper says: "When a generator and a motor are connected together and the motor is loaded, the generator poles advance and the motor poles retard; the angular difference is a measure of the power transfer. The angular difference produces a flow in current which tends to keep the machines in step. If the motor lags further behind it is out of step and will remain so until it comes back in step one full revolution later. Output is characterized by a series of current surges. A notching relay and "out of step" relay in combination may be used to prevent damage to synchronous machines that fall out of step.

A synchronous machine can run out of step indefinitely and damage will occur; the damper or starting windings will overheat. Or you can get mechanical resonance of the rotor and shaft which will form a torsional pendulum with the out of step surges. Duo-directional watt relays and an overcurrent relay with their contacts in series can be used to detect this condition. Such a relay follows the power oscillations and makes contact alternately in the positive and negative direction and steps up the notching relay on each impulse. The notching relay can be several relays in step (a counting chain of auxiliary relays). The relays would be reset by a timer if the requisite number of notches were not achieved in say 0 to 10 seconds (Crichton, 8).

know when the sources were in synch and could be switched on line.^{hh} Roger Nichols described the effect of switching an unsynchronized generator on line as a huge "WHOOOMP" that would shake the turbine hall to its very foundations.¹¹⁴

Another non-black box technique was used for summing up all the power generated in a given time period. The Lincoln Thermal Converter was a device for totalizing the power from all the generators. It converted voltage and current to heat. Proportionally accurate fractions of the voltage and current from each generator were detected through potential and current transformers. This power, representing a small but accurate analog of the power being generated, was fed into a heating coil placed in an insulated box. Each generator was represented by a heating coil in the box. The temperature in the box was detected by a thermocouple which was connected to a strip chart recorder which summed up all the power being generated as heat.¹¹⁵

BOILERS-1944:

World War II placed severe demands on the railroads nationwide. In addition to its normal commuter and freight

^{hh} A Synchroscope was used to indicate the angle of phase difference between two sources of emf (voltage) to which it was connected. It indicates that the starting machine is running faster or slower than the running machine. Cos Cob's Synchroscope was a split phase bipolar synchronous motor with separate AC excitation (UCONNHM&A).

operations, the New Haven moved troop trains and war material. Additional power was needed to meet these new demands. In 1942 the railroad obtained the necessary priorities, and in 1944 it completed the installation of a fifth pulverized-coal boiler, number 904. The unit was made by Riley Stoker and had a capacity of 150,000 lbs. of steam per hour. It also had a Cottrell electrostatic precipitator to reduce emissions.¹¹⁶

THE DECLINE OF THE COS COB POWER PLANT:

Capital for electrification was always in short supply and adversely affected the New Haven's plans to electrify the lines from New Haven to Boston and Springfield. Outside power purchases had been underway since 1915.¹¹⁷ In 1926 the New Haven entered into an agreement with Connecticut Light and Power to exchange surplus power. Two 60-to-25 cycle, 5000-kw frequency converters were installed at Devon, Connecticut, and one at New Haven to convert power.¹¹⁸ Still, there was insufficient power to electrify all operations, and freight operations over the Hell Gate Bridge route, for instance, continued under steam until 1927.

During the great depression, the New Haven decided to dispense with reserve electrical capacity. It added more locomotives to finally banish steam from under the catenary. During these years the Cos Cob equipment was ageing and operating

without an adequate reserve.

After it came out of bankruptcy in 1947, the New Haven was plagued by takeover battles that resulted in a series of managements whose primary interest was in financial manipulation rather than railroad operations. In April 1954, Patrick B. McGinnis replaced F.C. Dumaine Jr. as president after an impressive stock-proxy battle. By that time the Cos Cob power plant and the electric transmission system were in serious need of maintenance and capital improvement. McGinnis was supplied with biased data which showed the cost of re-electrification to be two and one-half times greater than it should have been.^u Rather than make the investment, McGinnis set out to dieselize the New Haven, using General Electric FL9 diesel-electric locomotives. The objective was to operate an engine that could haul trains from Boston to New York without the need for switching to an electric locomotive at New Haven. The FL9 had a diesel engine that powered an on-board generator which provided electricity to its traction motors. When traveling within the New York Central's third-rail zone, the FL9 extended a contact shoe, turned off the diesel and ran the traction motors directly on DC

^u The McGinnis administration quoted \$ 20 million as the cost of replacing the equipment at Cos Cob. In fact, \$ 20 million was the estimate of the cost of a plant which would supply enough power to supplant all power supplies--Cos Cob and commercial. Magnifying the flawed numbers, the 20 million dollar estimate was taken to be the cost of building a small plant that would supply only 30 percent of the railroad's needs as compared to the 62 percent that Cos Cob was actually supplying. (Pinkepank 1964:23)

power taken from the third-rail.

As diesel engines replaced electric locomotives, the system load on Cos Cob dropped from 210,000,000 kwh in 1956 to 100,000,000 in 1960 and 80,000,000 in 1961.¹¹⁹ By 1962 only seven electric passenger locomotives were functional and freight operations were completely dieselized.

McGinnis was a master at managing public relations. His plan to run a high-speed lightweight train from Grand Central to a suburban Boston station at Route 128 in two and one-half hours captured public imagination and positively influenced his proxy fight to take over the New Haven. In an attempt to realize the goal, he purchased three experimental high-speed trains, none of which was able to qualify for regular service. The promises remained unfulfilled and eventual public outcries over dirty cars, lack of maintenance and poor service forced McGinnis' resignation in 1956. His position was taken over by George Alpert, a lawyer who had no experience in railroad operations.

By 1960 it was evident that the dieselization program had been a major mistake. The first FL9 locomotives used in the third-rail zone had a tendency to lose their electrical contact shoes and catch fire. Further deliveries of FL9's were delayed until the design could be modified. It was clear that overhead had not been reduced by cutting out most of the electric locomotives.

The capacity of Consolidated Edison's Sherman Creek Station

was not enough to run the whole system. The connection with Connecticut Light & Power could not be terminated because Cos Cob would then have to provide peaking power as well as base load. In addition, the New Haven was obligated by contract to buy a minimum amount of power from the commercial suppliers, or pay for power not used. Cos Cob's situation had to change from one of supplying too much electricity for the safety of its ageing boilers and turbogenerators, to a status of supplying too little power for efficient operation. By 1956 management started to restore electric freight service to even out the load and bring down the cost of electricity. By that time there were few electric locomotives left. Most had been stored without protection and had been damaged by the weather and vandalized.

The New Haven once again entered bankruptcy in July of 1961. Alpert left his post, and a committee of trustees took over operations. They were able to purchase suitable used locomotives from both the Norfolk & Western and the Virginian railroads and maintain an economical cost of generating power at Cos Cob.¹²⁰

In 1908, the bankrupt New Haven became part of the Penn-Central. The Penn-Central had no desire to operate a deficit-ridden commuter service and wanted to discontinue the commuter operation altogether. New York and Connecticut agreed to make up any operating deficits and pay the Penn-Central a management fee to continue commuter service. When Penn-Central became insolvent and, along with several other bankrupt lines, formed the

Consolidated Rail Corporation (CONRAIL) the states continued the agreement with the successor corporation. New rail equipment was purchased by the states with 80 percent federal funding.¹²¹

The 1970s was a difficult time for commuters, the Cos Cob power plant, and the Greenwich residents who lived nearby. Years of deferred maintenance took their toll. Boilers were plagued by tube failures. After the morning rush, the men had to force cool boilers, take the steam tubes out, clean or replace them, then test and put everything back into service in time for the evening rush. Typical temperature within the "cool" boilers was about 150 degrees F. while the replacements were in progress. It was so hot the men would often burn the soles of their shoes off.¹²² Trains ran with the air conditioning in every other car turned off, or they were restricted to slow acceleration to conserve power. Both the commuters and the schedule suffered.

Under the Federal Clean Air Act each state was required to submit a plan to attain certain air-quality standards.¹²³ Connecticut's plan was approved on May 31, 1972. The Clean Air Act increased public awareness about the dangers of poor air quality. It also strengthened government's ability to eliminate or mitigate sources of pollution. By this time, Cos Cob's aging boilers and the increasingly poor quality of coal were causing serious environmental problems. Portions of Long Island sound were regularly blanketed with fly-ash. Officials were bombarded with complaints. A resident of Mead's Point called to say she

sent a white poodle into the yard every morning and a black one came back each night.¹²⁴

In 1974 the Town of Greenwich sued Connecticut and the Connecticut Department of Transportation, contending that operation of the plant resulted in pollution which exceeded allowable levels. The State argued that rail service under the agreement with New York was an interstate matter exempt from the regulations. The Connecticut Supreme Court agreed with the State that an interstate compact was excluded from state regulations.

The federal Environmental Protection Agency then declared that the Connecticut air quality plan was deficient because the state did not have the legal authority to carry out its orders. Revised regulations giving the state authority to regulate Cos Cob went into effect on June 30, 1975 and the Town of Greenwich sued once again, this time the co-plaintiff was the federal government.¹²⁵

The suit was successful and the Environmental Protection Agency issued an order requiring the plant to terminate operations by September 15, 1978. The system was ordered to be connected to a commercial electric source within 32 months. However, conversion was not even started until April 1978, because of a delay in obtaining funds from the Urban Mass Transportation Administration (UMTA) which was financing the changeover.¹²⁶

The legal record does not convey the frustration and sense

of futility felt by the Cos Cob operating engineers, the EPA regulators, the legal officials of New York and Connecticut and the public toward the Cos Cob plant during this period. It could be summarized as one government agency ordering another government agency to accomplish a change that would require considerable capital expenditure. However, neither agency was responsible for providing the funding. The responsible federal agencies and state legislatures were agonizingly slow in providing the necessary capital.

Through all the hearings, litigation and political maneuvering, the workers and operating engineers at Cos Cob kept the plant operating. They saw their job as getting some 30,000 commuters a day to work and sincerely believed that mission was far more important than the annoying pollution problem in the vicinity of the plant. They worked long hours under conditions of murderous heat, humidity, coal dust and fly-ash to keep the railroad running. To serve the commuters and the business community, they patched, repaired, reconstructed and resurrected antiquated equipment. There was a sense of pride and stubbornness that kept them going. Cos Cob was a "family" operation and you didn't let the plant down any more than you would let down your own family.

Upper management wanted to close Cos Cob as quickly, as did the court. R. J. Phillips, CEO of CDOT rail operations said:

Cos Cob is not only environmentally objectionable, it is

also a first-class maintenance headache and a very expensive one which we share with the state of New York. It behooves us, believe me, to phase that out just as quick as the Lord will let us.¹²⁷

A coal strike in 1977 forced the plant to buy low-grade reserve coal. The coal was fine and dusty and blackened Long Island Sound, adding to the environmental problems of the plant. It had been sitting around for years and was contaminated with old motors and scrap tools which damaged the crushers.¹²⁸

In 1979 the Connecticut Department of Transportation and Conrail entered into a consent order that required shutdown of coal-fired boilers 902 and 903. Portable or "package" boilers burning natural gas or number 2 fuel oil were to provide steam. Boiler number 904 had to be converted to oil or gas and could only be used if the package boilers were running at capacity. Shutdown of Cos Cob was made contingent on conversion of all railroad equipment to 60 cycles and receipt of federal funds to accomplish alterations.¹²⁹

Just about the time that the new portable boilers were installed, the turbo-generators gave out. A "twin" for turbine number 3 was found in good condition at Inland Steel Corporation, and it was purchased and installed in 1982.¹³⁰ Only twelve units of this type were built and four had been installed at Cos Cob.

OPERATIONS IN THE 1980s:

On May 22, 1982, the Cos Cob plant was designated an American Society of Mechanical Engineers/Institute of Electrical and Electronic Engineers Landmark. At the time, capacity was only 18,300 kw. The plant was generating 25-cycle power and feeding it into the transmission lines and catenary. The dispatch system had been upgraded; load dispatchers controlled operations of the distribution network and catenary system either directly or by remote control or through tower operators at other wayside substations. Control of all the substations was being transferred to New York City.¹³¹

Five coal-fired boilers remained intact. Boilers 900 and 901 had been cold since 1957. Boilers 902 and 903 had been shut down in 1980. Boiler 904, installed in 1944, had been converted to operate on natural gas or oil during 1981 - 1982 and was being used only on a standby basis. No coal had been burned since late 1980. Portable boilers, leased from Indeck and primarily fueled by natural gas, provided steam at 580 to 600 degrees F. and 325 psi to operate the plant.¹³²

Boiler water continued to be supplied from Mianus reservoir. Water treatment had been modernized in 1977 with the installation of ion-exchange water-softeners. Chelating agents were also used to bind and neutralize stray metal ions in the water. Preheaters raised water temperature to 218 degrees F. The water was then de-aerated, and most of the dissolved oxygen was removed. Water flowed to feedwater pumps that took it to the boilers. A new

signal power generating facility was built on the site of the west coal bunker.

The three turbo-generators were producing 18,300 kw of 25 cycle power, less than the rated output of 27,000 kw. Control room operators monitored the status of the power generating equipment and overall load demand and coordinated with the boiler operators, turbine operators and load dispatchers.

Three motor-generator sets converted 25 Hz power to 61 2/3 Hz for the signal system. The entire line from Woodlawn (Bronx) and Harold (Queens) to New Haven was fed from these motor generator sets, with back-up facilities at New Rochelle and New Haven. The section from Cos Cob to Woodlawn was changed over to 100 Hz signal power.¹³³

Management concluded that the cost of power generated by public utilities would be more reliable, competitive and eventually cheaper than power generated by Cos Cob. Railroad equipment standards changed, while design and materials improvements minimized the advantages of 25-cycle power and 60 cycle became the norm for railroad traction.

While low-frequency power was better for traction motors, it was not ideal for transmission. Often, power sags occurred, resulting in areas of lower power throughout the system. This caused lighting brownouts or loss of air conditioning. Changing to 60-cycle power resulted in what railroad electricians called greater 'stiffness,' or more equal power throughout the 61-mile

New Haven route. Line potential stabilized at 13,000 to 13,200 volts and allowed trains to run faster.¹³⁴

With 60-cycle power there was less overheating and wear and tear on the electric car fleet. Cos Cob voltage had, on occasion, slipped down to 9000 volts. With the reliability of utility-generated 60-cycle power, trains could meet faster schedules. Finally, the cost of Cos Cob electricity was 12 cents per kwh., while the cost of Northeast Utilities electricity was 7 cents per kwh.¹³⁵

Cos Cob endured deteriorating machines until 1983 when the Metro-North Commuter Railroad took over operations from Conrail. After 1983, the main task assigned to Cos Cob was to convert 60-cycle power purchased from public utilities to 25-cycle power for the railroad system.

Three 25-cycle motor-generator sets were bought to insure the power requirements of the New Haven line service could be met until the 60-cycle conversion could be completed and Cos Cob phased out. The replacement equipment and an outside source of 60 cycle peak power from Connecticut Light & Power allowed the line to run reasonably well after 1983.

The first official management announcement that Cos Cob would shut down came in July, 1986, with closure scheduled for the fall of 1986.

During the plant's eighty-year history the equipment became obsolete and continued production of 25-cycle power became

unnecessary since technological advances lessened the advantages of low-frequency electrical machinery. The advantages of a standard frequency outweighed the traction advantages of 25 cycle motors. Segment after segment of Cos Cob's territory was converted. The final two sections brought into the new power system were New Rochelle to Harrison on September 6, 1986 and Harrison to Cos Cob September 7, 1986.

The cost of electricity from public utilities was cheaper and more reliable. Still, in 1986 Cos Cob production was between 300,000 and 400,000 kw per day. It reached a low point of 130,000-kw/day in the summer of 1986. The plant actually stopped producing power on September 8, 1986. To guard against problems in the conversion to 60 cycle power, Cos Cob remained on standby in late September and all of October 1986.¹³⁶

The final crew size was forty-five men plus four supervisors.^j The Chief Engineer was Fred Mutino. Operating supervisor was Joseph Caccamo with thirty-eight years at the plant, the Mechanical supervisor was Gary Strutt, a fourteen-year veteran and the Electrical supervisor was Neil Sorenson who had sixteen years on the job.¹³⁷

THE PEOPLE BEHIND COS COB:

^j Crew size when Chief O'Donnell was operating the plant was 149 men.

The Westinghouse Electric & Manufacturing Company was the primary contractor for the electric locomotives, catenary track equipment and turbo-generators.

The contractor for construction of the original plant and its expansion in 1911 was Westinghouse, Church, Kerr and Company. The Westinghouse in this case was George Westinghouse's brother.¹³⁸ The New Haven's engineering department worked closely with the contractor during construction.

Calvert Townley was Chief Consulting Engineer on the project. Townley determined and analyzed operating conditions and requirements. William S. Murray, Electrical Engineer of the New Haven Railroad, was responsible for the design, project supervision and detailed execution of the venture.

Starting in 1918, the New Haven established a long-lasting working relationship with Gibbs & Hill, Inc., Consulting Engineers. Gibbs & Hill were involved in the Hell Gate Bridge electrification, expansion of electric service to New Haven, studies concerning electric rail service to Boston and Springfield, coal handling modifications, and all aspects of equipment operation, selection and maintenance at Cos Cob.

Mr. Sidney Withington was a New Haven Electrical Engineer who oversaw the plant modifications in the 1920-1940 period. Another prominent engineer in railroad electrification was B.G. Lamme, the Westinghouse engineer who developed the single-phase alternating-current railway motor in the early 1900s. Bion J.

Arnold and W.A. Blanck worked with Lamme to develop the single-phase system.¹³⁹

Cos Cob Plant Personnel:

One of the unusual features of the Cos Cob plant was its familial character. Family names that appear repeatedly over the years were Caccamo, Mutino, Marullo, Nichols, Rysinski, Weldon, Santoro and Tambascio. Sons replaced fathers, and there was a strong tradition of management personnel coming up from the ranks.¹⁴⁰

One individual's success story that coincides with the history of the Cos Cob plant from construction through its heyday was that of Lewis Grant O'Donnell. O'Donnell left school after the sixth grade in 1884 to go to work. He spent several years in the construction industry and eventually was hired as a laborer by Westinghouse, Church, Kerr & Company to work on the Cos Cob project. The New Haven hired him as a boiler room engineer on June 1, 1907, just about the time the first electric revenue service began. On January 3, 1911 O'Donnell was promoted to assistant chief engineer. By January 1, 1918 he was the first assistant chief engineer. He was named chief engineer on May 16, 1923 and remained in that position until he retired on June 15, 1940.¹⁴¹

O'Donnell developed several devices to make the work around

the plant safer and easier. In 1916 he received U.S. Patent 1,167,593 for an air-pressure lubricator. But his best-known innovation can still be seen on railroads all over the world. O'Donnell originated the concept of loading truck trailers onto railroad cars. This system delivered economical long-distance hauling, as well as the flexibility of local door-to-door trucking. His wife, Beatrice O'Donnell, (nee Best) dubbed the scheme "piggybacking" after a game she had played as a child in England. Railroad officials acknowledged his piggybacking scheme in a letter dated March 6, 1933.¹⁴²

In 1938 The New Haven was the first railroad to demonstrate piggybacking. The company's intent was to set up a major rail/truck terminal somewhere in southern New England. The New Haven, naturally, would operate the terminal and dominate freight operations. At first, the western trunk-line railroads were uninterested and the trucking industry fought the idea bitterly. Finally, on August 6, 1954, the Interstate Commerce Commission approved "piggybacking" on American railroads.

The western railroads soon discovered that they could piggyback into New England from their own terminals in New York and New Jersey, eliminating any need for the New Haven to be involved in their freight operations.

Fred Mutino was the last Chief Engineer. Over his thirty-eight year career he worked his way up from coal-handler to chief. Fred's father, Peter, had started at Cos Cob in 1912 as a

boiler repairman. He stayed for thirty-five years. Mutino had sixteen relatives working at the plant--as many as nine at the same time. From the plant's startup in 1907, until it closed, only five years went by without some member of the Mutino family working at Cos Cob.¹⁴³

Not everyone stayed at Cos Cob for their entire working lifetimes. The personnel records also show that there were many laborers who worked for a few months and then moved on. Workers who went on strike in 1922 had their actions noted on personnel records.¹⁴⁴

CONCLUSION

As the cities gradually became the domain of business and industry in the late nineteenth century, their inhabitants increasingly moved to outlying areas that became known as suburbs. With no environmental protection laws, air and water pollution were pervasive within the cities; the country beckoned with the promise of a better life. The trickle of people became a multitude when electric trains and streetcars made commuting inexpensive and convenient.

Within the story of New Haven electrification, the history of the Cos Cob power plant is an inspiring chapter in American railroading and technology. But more than that, it is a story of the triumph of the human spirit and inventiveness. From the technological standpoint it was brilliant, bold and daring. The New Haven and Westinghouse engineers pushed the available technology to its limits, they made mistakes, recovered and pushed the limits again. Men took pride in their reputations, put them on the line and failure was unthinkable. Remarkably, the system went from first power up in April, to revenue service in June of 1907, an inconceivably short test period for a venture of this scale.

The system saw use as a developmental undertaking as well as a working railroad. New Haven engineers were instrumental in developing and disseminating the knowledge needed to build

electrified railroads all over America.

Cos Cob is also a story of the achievements of the workers. They contributed to the operational design in the early years and later nursed an aging plant, badly in need of capital equipment improvements, through years of neglect. They kept steam up, turbines turning, generators pumping out kilowatts and trains running. People were able to work at highly paid jobs in the city and commute to a suburban lifestyle. The impact of suburbanization has had negative effects, but on balance it has benefitted the majority. Moving 30,000 to 40,000 people a day in and out of New York City was (and is) no small accomplishment. The achievement stands out when contrasted with Amtrack's nationwide present average daily traffic of 60,000 passengers.

The Cos Cob plant was a project and operating facility that had a major impact on American railroading. Its design, construction and operation were significant achievements in the chronicles of technology and a notable milestone in engineering history.

SELECTED BIBLIOGRAPHY
&
SOURCES CONSULTED

"Cos Cob Power Station, New York, New Haven & Hartford Railroad Company." Street Railway Journal 30(August 31, 1907): 308-316.

"Information for Inspection Party - New York and Vicinity" Archival collections: I.G. Davis to (Charles L). Beach, in University of Connecticut Archives, President's Office Records, Historical Manuscripts & Archives, University of Connecticut Library, (December 15, 1921): 1-2. (UCONNHM&A).

New York, New Haven & Hartford Electrification. Special Publication No. 1698. East Pittsburgh, Pennsylvania: Westinghouse Electric & Manufacturing Company, 1924, 1-43. (WE&MC).

Regulators for Generator Voltage Control. Special Publication No. 1734. East Pittsburgh, Pennsylvania: Westinghouse Electric & Manufacturing Company, 1929.

The Cottrell Process of Electrical Precipitation. Bulletin 201. New York: Research Corporation, 1929. (UCONNHM&A) File 17-2.

Regulators for Generator Voltage Control. Pittsburgh: Westinghouse Electric & Manufacturing Company, 1929. (UCONNHM&A).

"Improving Performance at Cos Cob Station." Power Plant Engineering (May 1935): 1-4.

The New Haven Railroad - Summary of Engineering Services Rendered by Gibbs & Hill, Inc. New York, February 21, 1949, 1-7. (UCONNHM&A).

Cos Cob Plant Tour ASME/IEEE Landmark Designation Ceremony. Cos Cob, Connecticut, May 22, 1982, 1-3. (UCONNHM&A).

Condit, Carl W. "Railroad Electrification in the United States." Proceedings of the IEEE 64(September 1976): 1350-1359.

Coster, E. H. "The Cos Cob Power Plant of the New York, New Haven & Hartford Railroad." Electric Journal 5(January 1908): 5-17.

- Cravath, James R. and Harris C. Trow. Electric Railways. Chicago: American School of Correspondence, 1907.
- Crichton, Leslie N. "A System out of Step and Its Relay Requirements." Electrical Engineering (October 1937). (UCONNHM&A).
- DeLony, Eric. Landmark American Bridges. New York: American Society of Civil Engineers, 1993.
- Desmond, Kevin. A Timetable of Invention and Discovery. New York: M. Evans & Company, Inc., 1986.
- Fazzalaro, James. History and Issues surrounding the Conversion and Phaseout of the Cos Cob Generating Plant on the New Haven Rail Line, Connecticut Document L55 BP No. 51. Hartford: Connecticut General Assembly, 1981, 1-30.
- Gibbs & Hill. The New Haven Railroad Summary of Engineering Services Rendered by Gibbs and Hill, Inc. New York: Gibbs & Hill, 1949, 1-7.
- Greenhill, Ralph. Engineer's Witness. Boston: David R. Godine Publisher, Inc., 1985.
- Haelig, Arthur W. M.D. "An Account of the Cos Cob Plant 1906-1965." in "Heavy Electric Traction." Grenada Hills, California: 1965. Document is a chapter from an unpublished manuscript; Private collection of Robert Vogel, 1-22.
- McHenry, E.H. "Electrification of the New York, New Haven and Hartford." The Railroad Gazette 43(August 16, 1907): 177-184.
- Murray, William S. "Electrification of the New York, New Haven and Hartford Railroad." Proceedings of the Connecticut Society of Civil Engineers 5(1913): 5 ff.
- Nichols, Roger. Interview by Robert C. Stewart. Greenwich, Connecticut: Cos Cob Documentation Project, June 28, 1993.
- Pacey, Arnold. Technology in World Civilization. Cambridge: The MIT Press, 1990.
- Handbook for Chemical Engineers. Ed. by John H. Perry. New York: McGraw-Hill Book Company, Inc., 1950.
- Pinkepank, Jerry A. "Why NH Reelectrified." Trains (August 1964): 21-26.

- Reich, Sy. "The Story of New Haven Electrification." Railroad
(April 1975): 40-51.
- Rogers, Warren O. "Extension of the Cos Cob Plant." Power 41(June
30, 1915): 40-51.
- Roth, Matthew W. and Bruce Clouette. "Cos Cob Power Plant."
National Register Nomination Form-HAER Inventory.
Washington, D.C.: U.S. Department of the Interior,
1989, 1-34.
- Riska, Gertrude. Chief of the Power Plant. Oral History Project.
Interview by Sallie Williams. Greenwich, Connecticut:
Greenwich Library, 1992.
- Sprague, Frank J. The History and Development of Electric
Railways. New York: McGraw Publishing Company, 1907.
- Stangl, Peter E. "An Era of Power." On Track Magazine
(September/October 1986): 1-7. New York: Metro-North
Commuter Railroad.
- Townshend, Doris B. Fair Haven, A Journey Through Time. New
Haven: New Haven Colony Historical Society, 1970.
- Turner, Greg. Connecticut Railroads-An Illustrated History.
Hartford: Connecticut Historical Society, 1986.
- Uher, Keith. A History of Land Transportation in the IEEE from
the Age of Electricity to the Computer Age. Pittsburgh:
Carnegie Mellon University Press, 1988.
- Vogel, Robert. "A Brief Historical Evaluation of the Cos Cob
Plant." Washington, D.C., Smithsonian Institution, Tms.
1977, 1-4.
- Weller, John L. The New Haven Railroad: Its Rise and Fall. New
York: Hastings House Publishers, 1969.
- Withington, Sidney. "The New Haven Railroad as a Pioneer in
Railroad Electrification." Proceedings of the New York
Railroad Club. New York: 1931, 1-9.
- Woodruff, Everett B. Steam Plant Operation. New York: McGraw-Hill
Book Company, 1984.
- Manuscripts & Archives at The University of Connecticut.

NEW YORK, NEW HAVEN & HARTFORD RAILROAD,
COS COB POWER PLANT
HAER No. CT-142-A
(Page 108)

Citation, Manuscript Collections, David Lane to Edward Ingrahm,
January 5, 1945 in Edward Ingrahm Papers, Historical
Manuscripts & Archives Department, University of Connecticut
Library (UCONNHM&A).

APPENDIX A

AC vs. DC

In the United States at the end of the nineteenth century, Thomas Edison and George Westinghouse were locked in what the press labeled, "The Battle of the Currents." In engineering circles, at meetings of professional societies, in technical journals, and in the daily newspapers, the merits and drawbacks of Edison's direct-current and Westinghouse's alternating-current systems were examined. Occasionally, Edison and Westinghouse themselves would acrimoniously debate the issue.

In September of 1882 Thomas Edison started up the first central station powerhouse. The plant was located on Pearl Street in New York City and generated energy for electric lighting in a one square mile block of lower Manhattan. The plant was the culmination of years of experimental effort in developing the direct-current system, including incandescent lamps, efficient dynamos, metering instruments and smaller components like fuses and lamp switches.

Edison's direct-current (DC) system spread rapidly. Sixty central stations were in operation by 1886--one hundred and twenty by 1887. Unfortunately, direct-current had a major liability; it could not be economically transmitted over even moderate distances. Central stations delivered either 120 or 240 volt direct-current. Large diameter copper wires were needed to minimize line losses due to resistance.

As the length of wire mains for lighting or trolley power increased, so did the resistance to current flow and the voltage dropped. Larger copper conductors offered less resistance to the passage of electricity so that voltage could be maintained at a level close to that being generated. But to maintain voltage at great distances, the cost of copper conductors would be prohibitive.

But the cost of copper wires restricted economical transmission to about one mile. Direct-current central stations had to be located near the consumers. This was especially true as copper prices, fueled by demand from a growing number of electrification projects, rose spectacularly after 1887.

Alternating-current was used for arc lighting before Edison and Westinghouse launched their campaigns for AC and DC. Arc lighting was a system for providing a brilliant point source of

white light. It consisted of contacting two electrodes together to strike an arc. The carbon electrodes were then pulled apart slightly and the arc continued to burn and give off a brilliant white light. Arc lighting was widely used for street lighting and theatrical lighting. The Westinghouse Electric and Manufacturing Company started experimenting with alternating-current in 1886. Extensive usage was limited by a lack of motors, transformers and metering devices capable of running on AC. Westinghouse's objective was to develop an AC system comparable to Edison's DC.

Westinghouse purchased the rights to the Gaulard and Gibbs' transformer that was developed in Europe, and contracted with William Stanley to improve and commercialize it. Stanley accomplished his task and developed a functional transformer. Alternating-current could now be raised to high voltages to minimize transmission losses and lowered to insure safe use in domestic and commercial applications.

The first commercial alternating-current plant started generating in Buffalo during 1886. In 1888 Westinghouse's chief engineer, Oliver Shallenberger, invented a method of metering alternating-current. Shallenberger's meter converted electrical energy into rotary mechanical motion of a disk at a rate that was in direct proportion to the amount of current being consumed. The same principle is used in contemporary watt hour meters. But alternating-current's applications continued to be limited by the lack of a practical motor. When Nikola Tesla patented an AC motor on May 1, 1888, Westinghouse recognized its value, purchased the rights, and hired Tesla to develop a commercial motor design.

With a meter, transformer, and motors, the alternating-current was a serious contender for domination of the electrical energy market. The Edison interests countered with charges that alternating-current was dangerous. Harold Brown, a New York electrical engineer, made a career out of "proving" the safety of DC by demonstrating unsuccessful electrocutions of animals using DC and successful ones using high voltage AC. Edison declared flatly that AC should be prohibited or at least restricted to less than 300 volts for safety. Brown's activities persuaded the state of New York to choose alternating-current for the first legal execution by electrocution. The alternator for this was furnished by Brown. Edison suggested that execution by electrocution be described by the phrase "being Westinghoused."

But to most of the engineering world, the advantages of a long distance high voltage alternating-current transmission system were indisputable. Conversion from DC to AC did not occur overnight, DC persisted in some cities until the post WWII period. The contest for dominance ended in 1895 when the first

transmissions of high voltage AC from a plant at Niagara Falls were sent to Buffalo some 20 miles away. Long distance transmission of alternating-current electricity had been established.

Corporate changes, driven by economics, occurred earlier. The Edison General Electric Company, a leading proponent of DC, merged with Thompson-Houston, an AC advocate, to form General Electric. Four years later, in 1896, General Electric and Westinghouse signed a patent exchange agreement. General Electric and the Edison interests had conceded the advantages of AC for long distance power transmission. Yet the AC/DC issue was far from being settled in the electric traction area.

Alternating and direct-current systems used to supply power for electric traction exhibit both advantages and disadvantages. Large scale electrification using direct-current would require an extensive series of trackside substations. But with alternating-current a physically large locomotive was required and these could not generate as much tractive power as the direct-current models.

APPENDIX B

FIRSTS FOR THE NEW HAVEN IN ELECTRIFICATION

1. The generation of single-phase power in large steam turbo units.
2. The development and installation of high voltage trolley capable of being exposed to the exhaust of steam engines.
3. The installation of an overhead conducting system on a four track railroad.
4. The development of a selective system of circuit breaker protection to handle frequent, high power short circuits.
5. The first use of gearless single-phase motors.
6. The combined use of AC and DC on locomotives.
7. The inauguration of a service without an extended trial period for the power house, line and locomotives.
8. The extensive undertaking of electric service by a steam railroad organization. (UCONNHM&A-IFIP).

APPENDIX C

A BRIEF CHRONOLOGY OF THE COS COB PLANT

- 1872 August 6; NYNH&H RR company formed.
- 1887 NYNH&H added Northampton, Naugatuck and Valley lines.
- 1893 NYNH&H added the Housatonic line.
- 1895 June 30; NYNH&H tests first electrification of a steam road.
- 1896 December 11; New Haven, Connecticut was the site of early electric freight experiments.
- 1898 NYNH&H consolidation completed. Railroad controls over 2000 miles of line.
- 1902 January 8 Wreck in New York Central's Park Avenue tunnel due to smoke & steam obscuring a signal spurs drive for electrification.
- 1903 New York legislature bans steam from NYC after 1908 (south of the Harlem River).
- 1905 First Baldwin/Westinghouse locomotive delivered to NYNH&H.
- 1905-1907 Westinghouse, Church, Kerr & Co. constructs Cos Cob Power Plant; cost \$1,130,000.
- 1905 Construction of catenary system starts.
- 1905 April; construction of Cos Cob started.
- 1907 Standard set for American RR power; 1 ph. AC: 25 Hz.: 11,000 v.
- 1907 First reinforced concrete 600,000 gallon water tank installed at Cos Cob.
- 1907 Summer-three 3000 kw generators installed.
- 1907 Twelve Babcock & Wilcox boilers with Roney underfeed stokers go on line they consumed 60 tons/day.

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1907 April; Energized line from Cos Cob to New York.

1907 June; First New Haven RR electric revenue service began.

1907 July 24; First regular train under electric power went from Grand Central to New Rochelle and returned.

1908 A 3330 kw turbo-generator and two boilers added to Cos Cob's battery.

1910 Biggest day ever for original plant-"Football Day" at Yale; demand at Cos Cob reached a peak of 16,000 kw.

1911-1912 Cos Cob Building enlarged.

1912 Four 4000 kw units installed.

1912 Fourteen Bigelow-Hornsby boilers installed; 200 psi.

1912 Cos Cob has a total of twenty-eight boilers: eight turbines with a capacity of 28,330 kw; generates 90,000,000 kwh/yr. using 3 lb. coal/kwh; 350 tons of coal/day.

1912 Electrification extended to Harlem River Branch.

1914 Electrification extended to New Haven.

1914 Electric system changed to a 22,000 v, three wire system.

1919 Outside storage and a Robins radial bridge for coal handling installed.

1919 Two outside bunkers added; 1000 tons each.

1923-1924 A second 600,000 gallon tank was built for water storage.

1923-1926 Three original generators removed-replaced with 9000 kw units.

1923 NYNH&H handles 17,600,000 passengers at Grand Central; has heaviest main line traffic of any main line electrified Railroad in the world.

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1926-1928	Two pulverized coal boilers (no's 900, 901) installed in east boiler room, coal consumption at 2.2 lb/kwh.
1927	Mianus River Pumping station built.
1933-1934	Fourteen boilers in east boiler room removed; Their capacity was 140,000 lb. steam/hr.
1933-1934	Two pulverized fuel boilers installed (no's 902 & 903); Their capacity was 220,000 lb/hr.; plant gained 80,000 lb./hour.
1933-1934	Bigelow-Hornsby boilers placed on standby.
1935	Belt coal conveyor to south bunker was installed. Replaced cable car system for water delivered coal.
1935	All older boilers decommissioned.
1936-1937	Bigelow-Hornsby boilers removed from west boiler room.
1938	Station steam pressure increased from 200-325 lbs. Coal consumption went down to 1.7 lb/kwh.
1940s	Cos Cob reaches peak power; 500,000 kwh/day.
1942-1956	Five boilers being operated; generator capacity 27,000 kw continuous to 30,000 kw intermittent. Output 120,000,000 to 160,000,000 kwh yearly - average coal consumption was 1.6-1.7 lbs/kwh annually, operating cost .525 cents/kwh.
1944	Riley Stoker boiler (904) installed. Steam capacity 150,000 lb/hr.
1944-1948	Modernized whole electric system.
1947	Gibbs & Hill designed a new coal handling system.
1948	Robins radial bridge scrapped; a bulldozer and two inclined conveyors replaced it.
1951	122,373,473 kwh annual output.

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1952-1953 Railroad scraps thirty-seven electric locomotives; starts dieselization program.

1958 59,000,000 kwh annual output.

1962 36,000,000 kwh annual output; operating costs 1.7 cents/kwh.

1963 Twelve "new" electric locomotives arrive. Load at 60,000,000 kwh/yr.

1965 Coal usage at 167 tons/day (360 tons/day was maximum)

1968 A reluctant Penn-Central takes over the bankrupt NYNH&H.

1976 Conrail was founded to consolidate several bankrupt eastern railroads, including Penn-Central.

1977 Severe air pollution problems caused by Cos Cob plant.

1978 Gas/Oil boiler conversion completed.

1980 February; 1000-ton west coal bunker demolished.

1980 All coal burning stopped.

1981 Turbo-generator No. 3 replaced with 'new' one from Inland Steel.

1982 With three remaining turbo-generators the maximum production was 27,000 kw, 25 Hz, 1 ph.

1982 Installed three motor generator sets (frequency converters) 25 hz to 61 2/3 hz for signal power.

1982 May 22; Cos Cob given Landmark status by ASME/IEEE.

1983 January; Metro-North activated.

1986 Production down to 300,000 to 400,000 kwh/day.

1986 Summer; Production down to 130,000 kwh/day.

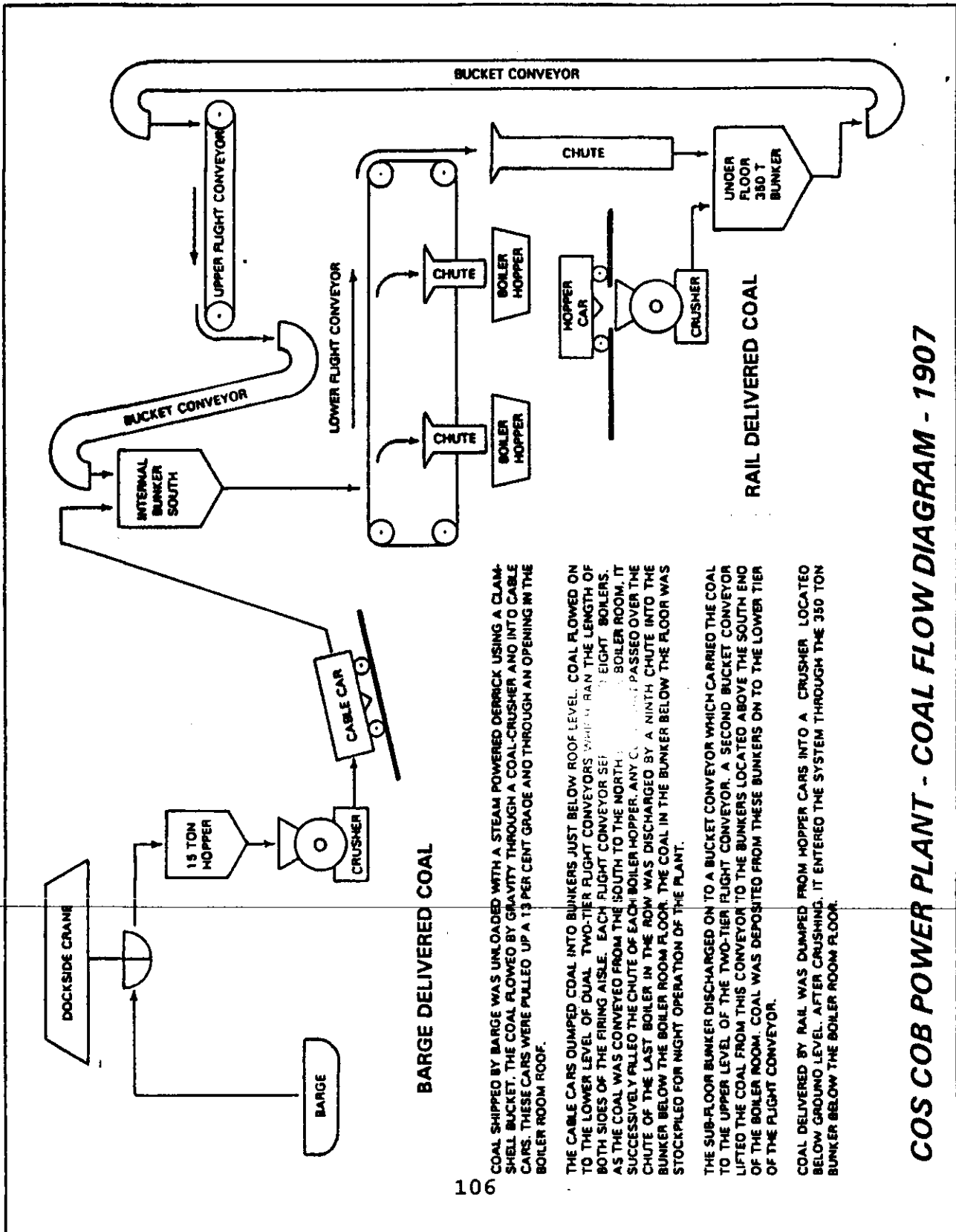
1986 Sept. 6; Stopped producing power, plant on standby.

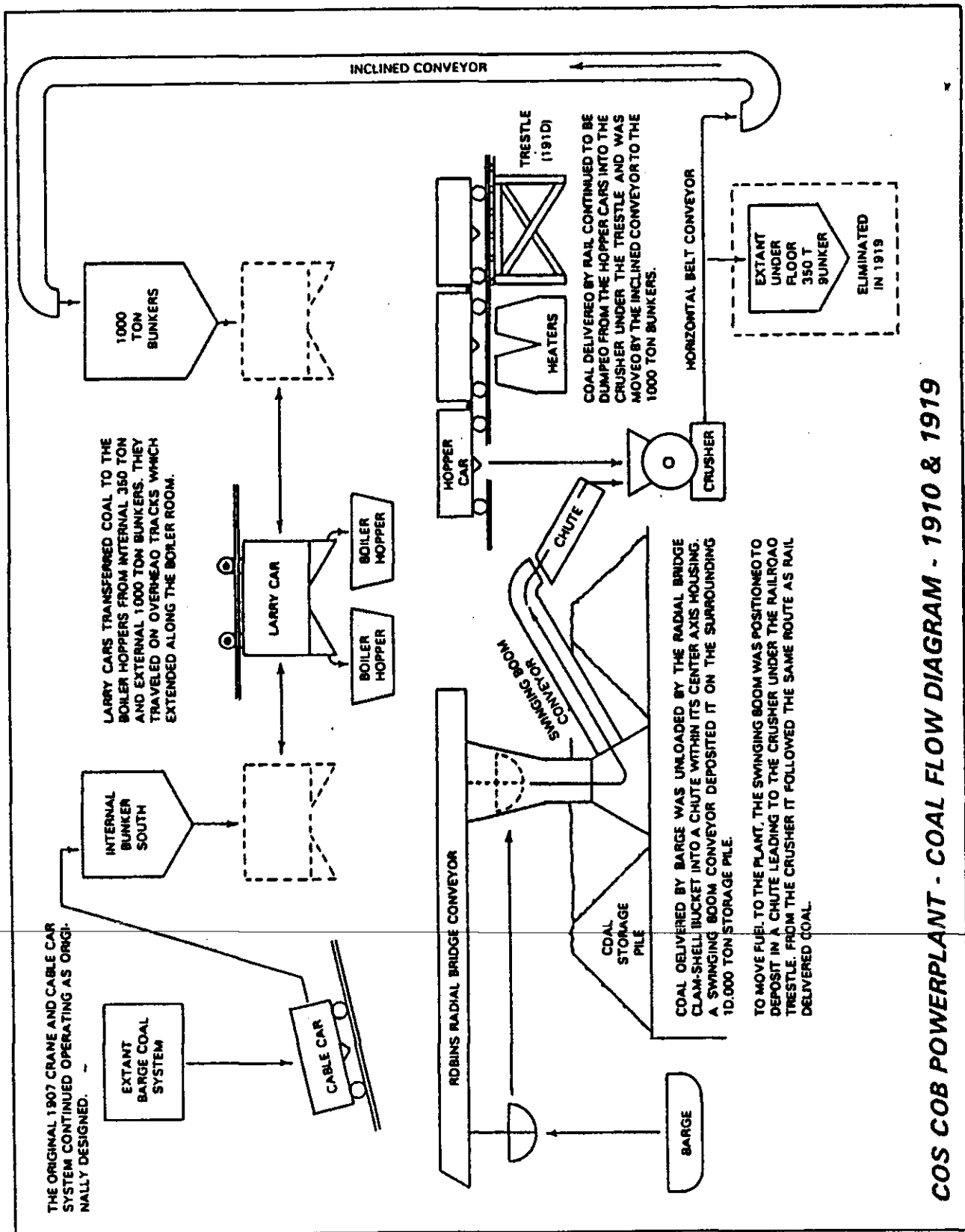
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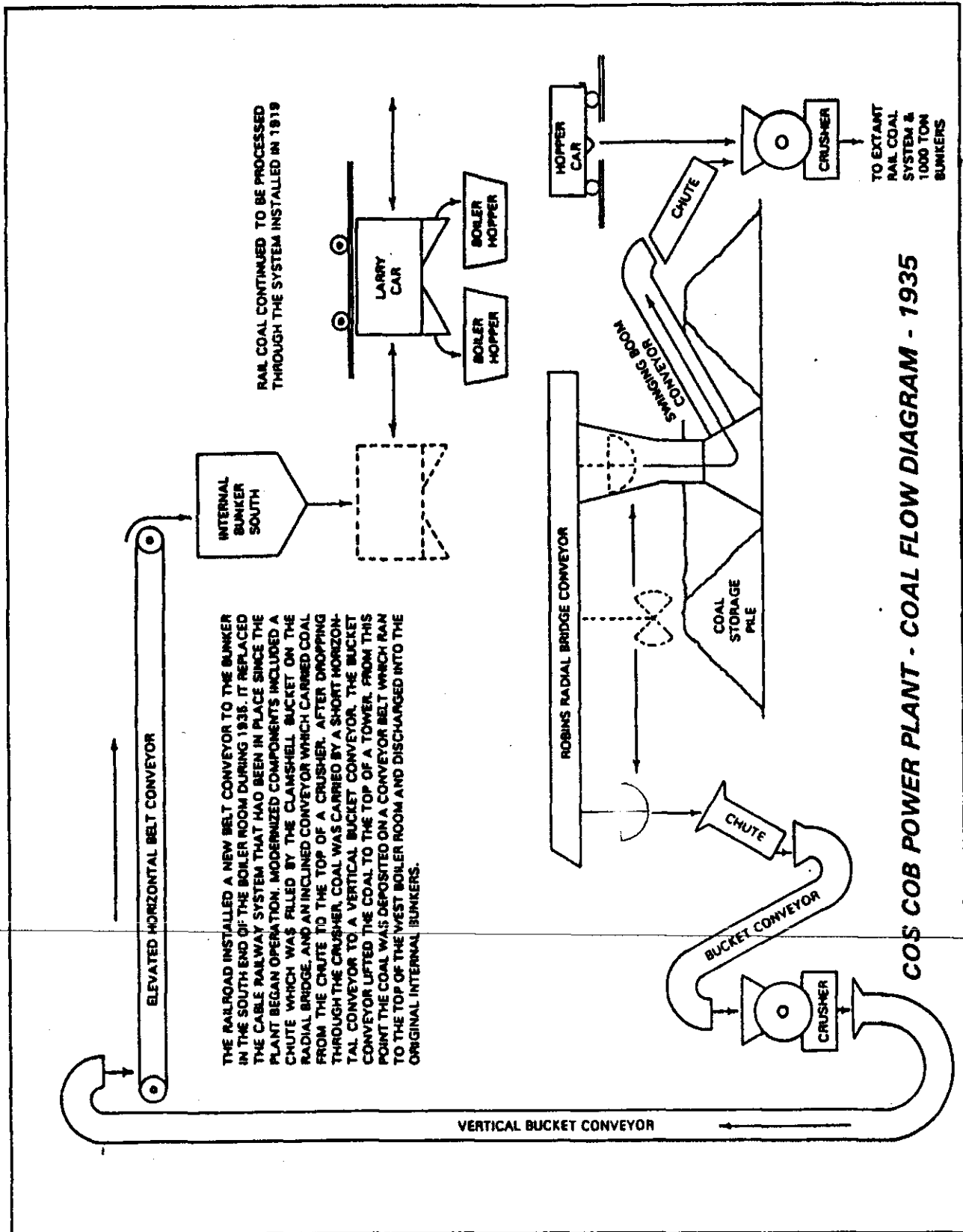
1986 Oct. 31; Plant shut down.

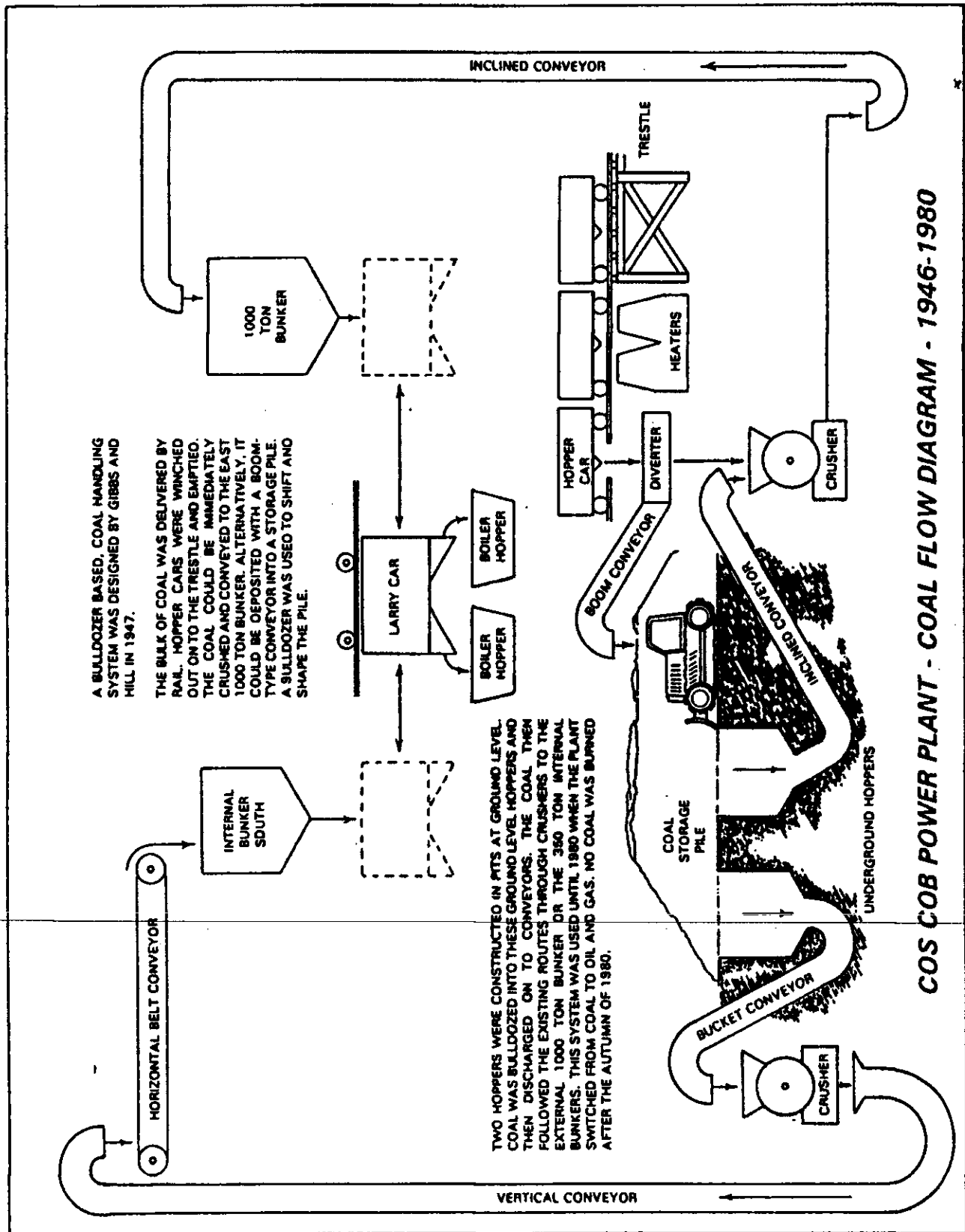
APPENDIX D

COAL OPERATIONS FLOW DIAGRAMS









COS COB POWER PLANT - COAL FLOW DIAGRAM - 1946-1980

LIST OF ABBREVIATIONS:

AC	alternating-current
CDOT	Connecticut Department of Transportation
CONNDOT	Connecticut Department of Transportation
DC	direct-current
hz	Hertz or cycles per second
IFIP	Information for Inspection Party
kva	kilovolt-amperes
kw	kilowatts
kwh	kilowatt-hours
SRJ	Street Railway Journal
UCONNHM&A	University of Connecticut Historical Manuscripts and Archives
UMTA	Urban Mass Transportation Administration
USEPA	United States Environmental Protection Agency
WCK&C	Westinghouse, Church, Kerr & Company
WE&MC	Westinghouse Electric & Manufacturing Company

REFERENCES CITED

1. New York, New Haven & Hartford Electrification, Special Publication 1698, (East Pittsburgh, Pennsylvania: Westinghouse Electric and Manufacturing Company, (WE&MC), 1924), 14.
2. Information for Inspection Party - New York and Vicinity, December 15, 1921, (New York: New York, New Haven & Hartford Railroad), 1 (UCONNHM&A-IFIP).
3. Robert M. Vogel, "A Brief Historical Evaluation of the Cos Cob Power Plant," Washington, D.C.: Smithsonian Institution, Tms., 1977, 3.
4. Peter E. Stangl, "An Era of Power," On Track Magazine, Special Issue (September/October 1986): 4. Metro-North Commuter Railroad Employee's Publication.
5. John L. Weller, The New Haven Railroad, Its Rise and Fall (Don Mills, Ontario, Canada: Saunders of Toronto, Ltd., 1969), 6.
6. Frank J. Sprague, The History & Development of Electric Railways (New York: McGraw Publishing Company, 1907), 1.
7. Ibid., 2.
8. Ibid.
9. E.H. McHenry, "Electrification of the New York, New Haven & Hartford," The Railroad Gazette 43(August 16, 1907): 177.
10. Arnold Pacey, Technology in World Civilization (Cambridge: The MIT Press, 1990), 168.
11. Kevin Desmond, A Timetable of Invention and Discovery (New York: M. Evans & Company, Inc., 1986), 1879.
12. Ibid., 1882.
13. Keith Uher, A History of Land Transportation in the IEEE from the Age of Electricity to the Computer Age (Pittsburgh: Carnegie Mellon University Press, 1988), 14.
14. Sidney Withington, The New Haven Railroad as a Pioneer In Railroad Electrification, XLI, no. 5 (New York: Official Proceedings of the New York Railroad Club, March 1931), 3.

15. McHenry, 177.
16. Withington, 3.
17. Ibid., 4.
18. Carl W. Condit, Railroad Electrification in the United States, 64, no. 9 (New York: Proceedings of the IEEE, September 1976), 1352.
19. McHenry, 177.
20. Ibid., 177.
21. Vogel, 1.
22. Condit, 1354.
23. Uher, 16.
24. Condit, 1355.
25. McHenry, 177.
26. Uher, 16.
27. McHenry, 177.
28. Ibid., 177.
29. Withington, 4.
30. McHenry, 177.
31. Sy Reich, "The Story of New Haven Electrification," Railroad Magazine (April 1975): 46.
32. James Fazzalaro, History and Issues Surrounding the Conversion and Phaseout of the Cos Cob Generating Plant on the New Haven Rail Line-Connecticut Document L55 BP No. 51 (Hartford: Connecticut General Assembly, 1981), 6.
33. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," Street Railway Journal 30(August 31, 1907): 312.
34. Matthew W. Roth, Cos Cob Power Plant, National Register Nomination Form (Washington, D.C.: Department of the Interior; HAER Inventory, 1989): 1-4 passim.

35. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 309.
36. Ibid., 308.
37. Robert Grzywacz, Architect, interview by author, Cos Cob, Connecticut, 12 July 1993.
38. Withington, 1.
39. Uher, 17.
40. E.H. Coster, "The Cos Cob Power Plant of the New York, New Haven & Hartford Railroad," Electric Journal 5(January 1908): 17.
41. Arthur W. Haelig, Heavy Electric Traction, Tms., 1965. Collection of Robert Vogel, Washington, D.C.: National Museum of American History, Smithsonian Institution, 13.
42. Haelig, 13.
43. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 312.
44. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 312.
45. Ibid., 312.
46. Ibid., 14.
47. Coster, 8.
48. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 313.
49. Haelig, 4.
50. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 311.
51. Ibid., 311.
52. Ibid., 309.
53. Ibid., 312.
54. Ibid., 312.

55. Ibid., 310.

56. Warren O. Rogers, "Extension of the Cos Cob Plant," Power 41(June 30, 1915): 362.

57. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 313.

58. Ibid., 314; Coster, 17.

59. Ibid., 310.

60. Ibid., 310.

61. WE&MC, 14.

62. Uher, 17.

63. Haelig, 12.

64. Coster, 14.

65. McHenry, 183.

66. Haelig, 13; and "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 310.

67. Ibid., 310.

68. "Cos Cob Power Station, New York, New Haven & Hartford Railroad Company," 314.

69. Ibid., 316.

70. McHenry, 179.

71. Coster, 16.

72. WE&MC, 10.

73. Ibid., 22.

74. Ibid., 12.

75. Ibid., 14.

76. Matthew Roth and Bruce Clouette, "Cos Cob Power Plant," National Register of Historic Places Registration Form (Washington D.C.: National Park Service, 1989), 7-3.

77. Ibid., 15.
78. Stangl, 6.
79. Gibbs & Hill Consulting Engineers, Wiring Diagram for Light and Power for Coal-Handling Equipment, Blueprint ID #6C-77, (New York: March 28, 1919).
80. Haelig, 15.
81. Rogers, 361.
82. Ibid., 360.
83. Ibid., 361.
84. Stangl, 6.
85. Roger Nichols, interview by author, 28 June 1993, Notes, HABS/HAER Recording Team, Cos Cob, Connecticut May-August 1993
86. Ibid.
87. WE&MC, 14.
88. Ibid., 1.
89. Haelig, 14.
90. Rogers, 358.
91. Ibid., 359.
92. UCONNHM&A-IFIP, 1-2.
93. Jerry A. Pinkepank, "Why New Haven Re-electrified," Trains (August 1964): 20.
94. WE&MC, 22.
95. Ibid., 18.
96. Fazzalaro, 7; Vogel, 2.
97. Haelig, 18.
98. Ibid., 13.

99. Ibid.

100. Gibbs & Hill, The New Haven Railroad-Summary of Engineering Services Rendered by Gibbs & Hill, Inc. (New York: Gibbs & Hill, February 21, 1949), 5.

101. Gibbs & Hill, 5.

102. Everett B. Woodruff, Steam Plant Operation (New York: McGraw-Hill Book Company, 1984).

103. Haelig, 5.

104. Haelig, 8.

105. Ibid., 5.

106. Ibid., 22.

107. Gibbs & Hill, 6.

108. Anonymous 1929 "The Cottrell Process of Electrical Precipitation" Bulletin 201 - Research Corporation, New York

109. "Improving Performance at Cos Cob Station," Power Plant Engineering (May 1935): 4.

110. Nichols, op.cit.

111. Haelig, op.cit., 15.

112. Nichols, op.cit.

113. Leslie N. Crichton, "A System Out of Step and Its Relay Requirements," Electrical Engineering (October 1937), passim, (UCONNHM&A).

114. Nichols.

115. The Lincoln Thermal Analyzer (Springfield, Illinois: Lincoln Meter Company, May, 1939). (UCONNHM&A).

116. Haelig, op.cit., 6

117. Haelig, op.cit., 19.

118. Pinkepank, op.cit., 21.

119. Haelig, op.cit., 20.
120. Pinkepank, op.cit., 26.
121. Fazzalaro, op.cit., 7.
122. Stangl, op.cit., 2.
123. Clean Air Act - 42 U.S.C. paragraph 1857 et. seq.
124. Stangl, op.cit., 2.
125. Lawsuits Civil B-76-193 (Greenwich v. CDOT) and Civil B-76-282) U.S. v. CDOT et. al.)
126. Fazzalaro, op.cit., 12.
127. Conference Concerning Notice of Violation Issued to Cos Cob Power Plant, USEPA July 30, 1975
128. Nichols, op.cit.
129. Fazzalaro, op.cit., 19.
130. Nichols, op.cit.
131. ASME/IEEE Designation Ceremony, May 22, 1982
132. "Cos Cob Plant Tour - ASME/IEEE Designation Ceremony, 1982," (UCONNHM&A).
133. ASME/IEEE, 1.
134. Stangl, 1986, op.cit., 4.
135. Stangl, op.cit., 4.
136. Stangl, 1986, op.cit., 4.
137. Stangl, op.cit., 6.
138. Charles Ruch, Archivist at Westinghouse Electric, Pittsburgh, Pennsylvania, Interview by author, HABS/HAER Recording Team, Cos Cob, Connecticut, June 29, 1993.
139. Uher, 15.
140. Stangl, 2.

NEW YORK, NEW HAVEN & HARTFORD RAILROAD,
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(Page 131)

141. Gertrude Riska, Interviewed by Sallie Williams as part of Oral History Project, in Chief of the Power Plant (Greenwich, Connecticut: Greenwich Library, 1992).

142. Lewis Grant O'Donnell, Cos Cob, Connecticut, letter to F.J. Wall, Vice President, Traffic Department, NYNH&H, March 6, 1933. Original letter in the collection of Gertrude Riska, Cos Cob, Connecticut.

143. Stangl, 2.

144. I.G. Davis, New Haven Railroad, letter to Charles L. Beach, December 23, 1925. Collection of the University of Connecticut Archives, President's Office Records, Historical Manuscripts & Archives, University of Connecticut Library. (UCONNHM&A).